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THE RANGE OF ELECTRIC SEARCHLIGHT PROJECTORS

THE RANGE OF ELECTRIC SEARCHLIGHT PROJECTORS

BY

JEAN REY

INGÉNIEUR CIVIL DES MINES, LAURÉAT DE L'INSTITUT

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INTRODUCTION

THE use of searchlight projectors both in the navy and with the land forces, is becoming more and more general. Not only has the number of such apparatus become considerable, but the types also have become largely varied and the size and power of the projectors keep steadily increasing.

In spite of this, no combined work has up to the present been undertaken dealing with the question of the range of projectors, and artillery officers or naval officers, who are thoroughly capable of calculating the range of their own apparatus, have nearly always ignored the range of illumination possible for searchlights under the varying conditions of service.

In the present book I have endeavoured to sum up the methods for range measurement, and, with the assistance of much information not previously published, the solution of the problem if not entirely elucidated, is at least advanced from a practical point of view.

In this connection, I must express my gratitude to my friend Professor A. Blondel, who, some twenty years ago, was the first to put forward a theory on electrical searchlights, and whose researches on the electric arc are universally known. He has helped me with his advice and has kindly allowed me to make use of some of his previously unpublished works, which it is to be hoped he will soon allow to be published.[1]

[1] M. Marsat, Engineer with the firm of Messrs. Sautter, Harlé & Co., prepared my most recent experiments, and has greatly helped me in the matter of the determination of the empirical laws concerning the electric arc. I herewith tender him my sincere thanks.

The study of the range of electric searchlights comprises first of all—

The determination of the luminous flux emitted by the arc; the extent of the distribution of this flux as it is received and reflected by the mirror of the searchlight; then the calculation of the amount of light projected at a distance, taking into account the size of the apparatus and the focal length of the mirror.

Once the amount of light projected at a distance by the searchlight is known, it becomes possible to approximately calculate its range of illumination by taking into account the coefficient of the atmospheric transparency. It then becomes possible to determine, for any given searchlight, the probability of being able to illuminate a certain position at a given distance, provided one is acquainted with the climate — that is, the average degree of transparency at that particular locality.

PROJECTOR RANGE

In view of the absence of any modern and original work in English on the range of searchlight projectors, and the urgent demand by our air, naval and military forces for information relating to the calculation of illumination and range of searchlight projectors, M. Jean Rey has kindly transferred to me the rights of translation and publication of this important work.

The subject is one of exceptional interest at the present time apart from its national importance. The chapter relating to the practical calculation of ranges in connection with warships, fortresses, trenches, etc., and also the appendix "C" on the subject of optical illusion on the Western Front in Flanders during the present War, will be found to be particularly valuable. It will be observed that the formulæ, constants and curves employed in the calculation of illumination and range throughout this work, are based on the standard distance of 1,000 metres or a kilometre. It was therefore decided to adhere to these measurements in the translation, especially as our Expeditionary Forces are now familiar with metric measurements. In order to facilitate the conversion of the measurements from metric to British units the necessary multiplying constants are given below:—

Millimetres multiplied by or divided by	·03937 25·4	=	inches.
Centimetres multiplied by or divided by	·03281 30·4795	=	feet.
Metres multiplied by	3·281	=	feet.
Metres multiplied by	1·0936	=	yards.

Kilometres multiplied by	1,093·6	=	yards.
Kilometres multiplied by	·6214	=	miles.

The whole of the information relating to projector illumination is in connection with the standard forms of lamps burning ordinary carbons, and not with the more recent developments of the "Harrison," "Sperry," and "Beck" projector lamps. It is hoped, however, that the test results obtained from the actual working of these latest designs of projector lamps with largely increased powers of illumination will be published in a future edition.

Numerous experiments have been carried out with carbons of special construction, in order to obtain a higher illumination with a given power consumption. M. Jean Rey has informed me that Messrs. Harlé & Co. have now succeeded in manufacturing special carbons which will burn in a standard form of projector lamp, and the resultant illumination is from three to five times that obtained with ordinary carbons with the same power consumption.

Owing to Government restrictions at the present time it is impossible to give further details in this edition.

J. H. JOHNSON, M.Inst.E.E., Assoc.A.I.E.E.

THE RANGE OF ELECTRIC SEARCHLIGHT PROJECTORS

PART I

The Illumination from Electric Searchlight Projectors

CHAPTER I

DETERMINATION OF THE LUMINOUS FLUX EMITTED BY THE ELECTRIC ARC

General Observations. — The source of light in modern searchlights is created by an arc lamp, the carbons of which are horizontal and placed within the principal focal axis of the mirror or reflector. The positive carbon is fitted at the front end of the projector and the negative carbon (of a smaller diameter) next to the mirror, so as to uncover as much of the luminous crater of the positive carbon as is possible. The volume of light is almost entirely given out by the incandescent crater, and the luminous flux due to the flame or to the incandescent point of the negative can be ignored in practice.

For many years, from the time of the invention of searchlights by M. Louis Sautter in 1867 until the year 1895, the lamps of searchlights were arranged with inclined carbons. The utilisation of the luminous flux, especially with a long focal length, was more advantageous than with horizontal carbons, but the work of regulating was more delicate and demanded a more expert staff. That is the

reason why horizontal carbons have superseded the inclined carbons.

Attempts have recently been made, by the use of carbons of a special composition, to obtain a crater as concentrated as possible, and with the help of negative carbons of small diameter and heavily coppered it has thus become possible to increase the total useful luminous flux to quite a considerable extent. On the other hand, these carbons of small diameter rapidly burn away, which has necessitated the manufacturers of searchlights to make use of special devices, such as the glimmer light, in order not to seriously reduce the burning hours and to avoid frequent attention to the renewal of the burnt-out carbons.

The radiation from the crater of a positive carbon is in general accordance with a well-known law, called the "Lambert Law." The light intensity in every direction of space, is equal to the product of the mean intrinsic brilliancy of the luminous crater (obtained by its projection on a plane perpendicular to the given direction) and the area of the crater.

When the luminous intensities of an electric arc are measured according to the various directions in space, it will be seen that the numbers group themselves perfectly, according to the Lambert Law, in every part of the space where the shadow of the negative carbon and holder does not exist—that is to say, up to approximately 40° to 45° of the vertical plane perpendicular to the axis of the carbons. From the moment that the influence of the negative begins to be felt, the luminous flux emitted by the arc is partially obscured, and when at the position of the axis of the carbons, that is to say to the mirror, the amount of light received is practically *nil*, as at this point the shadow of the negative forms a complete screen.

CURVE OF THE DISTRIBUTION IN SPACE OF THE LUMINOUS FLUX EMITTED BY AN ELECTRIC ARC.—Two methods may be followed for the measurement of the luminous flux emitted by an electric arc.

The first consists in measuring the average specific brilliancy of the crater and its surface; the other, the intensity according to the various directions in space.

The first method gives an estimate of the luminous flux, which is more theoretical than practical, for it assumes that the flux emitted by the crater is distributed in space as if the negative carbon had been suppressed. It may therefore be said that it gives the measurement of the luminous flux emitted by the arc, but part of this flux is always obscured by the negative carbon.

The second method leads to an estimate of the luminous flux as it is received by the reflector at its solid angle of contact.

First Method.—MEASUREMENT OF THE BRILLIANCY AND OF THE CRATER AREA.—In a note which we presented in July, 1902, to the International Society of Electricians in Paris, we summarised the principal works, which had already been published at the time, dealing with the intrinsic brilliancy of the large continuous current arcs.

In this survey we also gave an account of our own experiments carried out in the laboratory of the Sautter-Harlé Works.

By large continuous current arcs we mean those arcs which exceed, say, 10 amperes, *i.e.*, arcs other than those used for industrial and public lighting. In practice, searchlight arcs are never below 25 or 30 amperes, and they are used up to 200 and even 250 amperes, more especially for those searchlights employed in the fortification works along the coasts.

In the afore-mentioned note we pointed out the methods which have enabled us to measure the intrinsic brilliancy of an electric arc. These methods, which Professor Blondel was the first to bring forward and which he had already applied in respect of arcs of less importance, have enabled us to determine the brilliancy of the crater.

We have thus ascertained that this brilliancy varies with the intensity, and that it increases to a certain extent with the same carbons, if the current is increased.

This increase of the brilliancy with the current, which we have always confirmed in the numerous measurements carried out since the previously mentioned note, had already been observed by various authors. It is indisputable (at least in so far as the human eye is concerned when taken as a measuring apparatus) that the photometrical value of the brilliancy is the only one of interest from the point of view of military searchlights.

However, the methods employed for measuring the brilliancy to which we have just alluded all admit a certain element of uncertainty, which may introduce considerable variations in the numerical results obtained. Whatever may be the method followed, it is most difficult, when measuring the intrinsic brilliancy of a crater, to determine its actual average value. The operator always endeavours to place his measuring apparatus in the most brilliant section of the luminous flux which is projected. This leads to a tendency to increase the figures obtained for the average brilliancy.

The best method consists in replacing the photometer by a photographic plate, provided that the latter possessed the same scale of sensibility as the retina, and did not subsequently make it necessary to use special photometers for the measurement of the tints obtained.

It may therefore be said, that the measurement of the

average brilliancy of the crater is always adversely affected by a coefficient of error, often very high, and which in itself largely varies with the observer.

The calculation of the luminous flux, based on the measurement of the brilliancy of the crater, therefore participates in the same uncertainties as that measurement itself. For this reason we have recognised that it is preferable in calculating the average brilliancy to measure the actual flux and more especially the total theoretical flux emitted by any given crater, assuming the suppression of the shadow from the negative carbon.

It is therefore this second method which will now be considered.

The value of the average intrinsic brilliancy of the crater of an electric arc varies, not only with the intensity of the current, as we have previously observed, but also with the diameter of the positive carbon and the amount of electric energy absorbed by the arc itself.

These various points render the determination of the value of the intrinsic brilliancy far more complex, and it is only by taking them into account that it becomes possible to explain certain anomalies, which we have ascertained during our preceding experiments, without being able to find out their cause.

In order to calculate the theoretical flux it is necessary to know the working area of the illuminated crater. The determination of the working area of a crater in any given case—that is to say for a positive carbon, the diameter of which is known and for a given intensity—is not an easy measurement, as might be supposed. It is always a delicate matter to estimate the illuminating surface of a crater, or, rather, of its section, projected on a plane perpendicular to the axis of the carbon. The brilliancy of the crater is not the same over its whole area; it is always somewhat

less in the central portion, which corresponds to the core, as cored positive carbons are the only ones adopted for searchlight lamps. On the extreme edges of the crater the brilliancy rapidly lessens, but there is a well-defined limitation between the lighting part and the non-lighting extremity. It is therefore necessary to take a large number of average values when projecting the reflections of the crater on to a screen by means of a prism or a lens, and account must be taken of the angle of the reflection.

During the last two years we have had occasion to carry out some very complete series of experiments, comprising more than one thousand measurements of photometrical intensities.

During the whole of these experiments we have established the dimensions of the crater, and we have fixed the averages, which cannot differ greatly from the exact values.

We have thus been able to determine the empirical relation which determines the dimension of the working area of the crater for a given diameter of the positive carbon and a given intensity. This relation, moreover, is identical with the empirical formula established by us in our note of 1902, only that the coefficient has been determined with greater exactness. We shall refer to it again later.

Second Method. — MEASUREMENT OF THE INTENSITY ACCORDING TO THE VARIOUS DIRECTIONS IN SPACE.— Several different methods may be employed for the measurement of the intensity of an electric arc, according to the various directions in space.

An attempt may be made, with the aid of the lumenmeter conceived by Professor Blondel, to measure in a

specified solid angle the whole of the luminous flux which it encloses.

On the other hand, one can measure the intensity according to the principal directions in space by using a set of mirrors, which reflect on to the photometer the rays they receive according to the various directions. When mirrors are used it is necessary first of all to measure their efficiency.

By taking suitable precautions to always simultaneously measure the luminous intensities photometrically in two directions, which are symmetrical in relation to the axis of the carbons, so as to take into account the variations of the arc and the angle of the crater, an experienced operator succeeds in establishing averages which never vary by more than 1 to 2 per cent.

In Fig. 1 are given the results of experiments carried out on an arc of 100 amperes, working at 54 volts at the terminals of the carbons.

For these experiments the positive had a diameter of 24 millimetres and the coppered negative 11 millimetres.

The current intensities are shown every 10° from the axis of the carbons to a distance of 90° from this axis; they are shown on the diagram at their average values in decimal candle-power.

The intensity curve OM has the shape of an ellipse, the axis of which is at an angle of about 40° to that of the carbons.

The direction of the axis of the carbons is shown by the straight line OBD; OA is the line perpendicular to this axis.

We have not taken into account a point measured at a distance of 90° from the axis of the carbons, on the straight line OA, where the intensity was not *nil*, but attained 3,200 decimal candle-power. The intensity in that direction

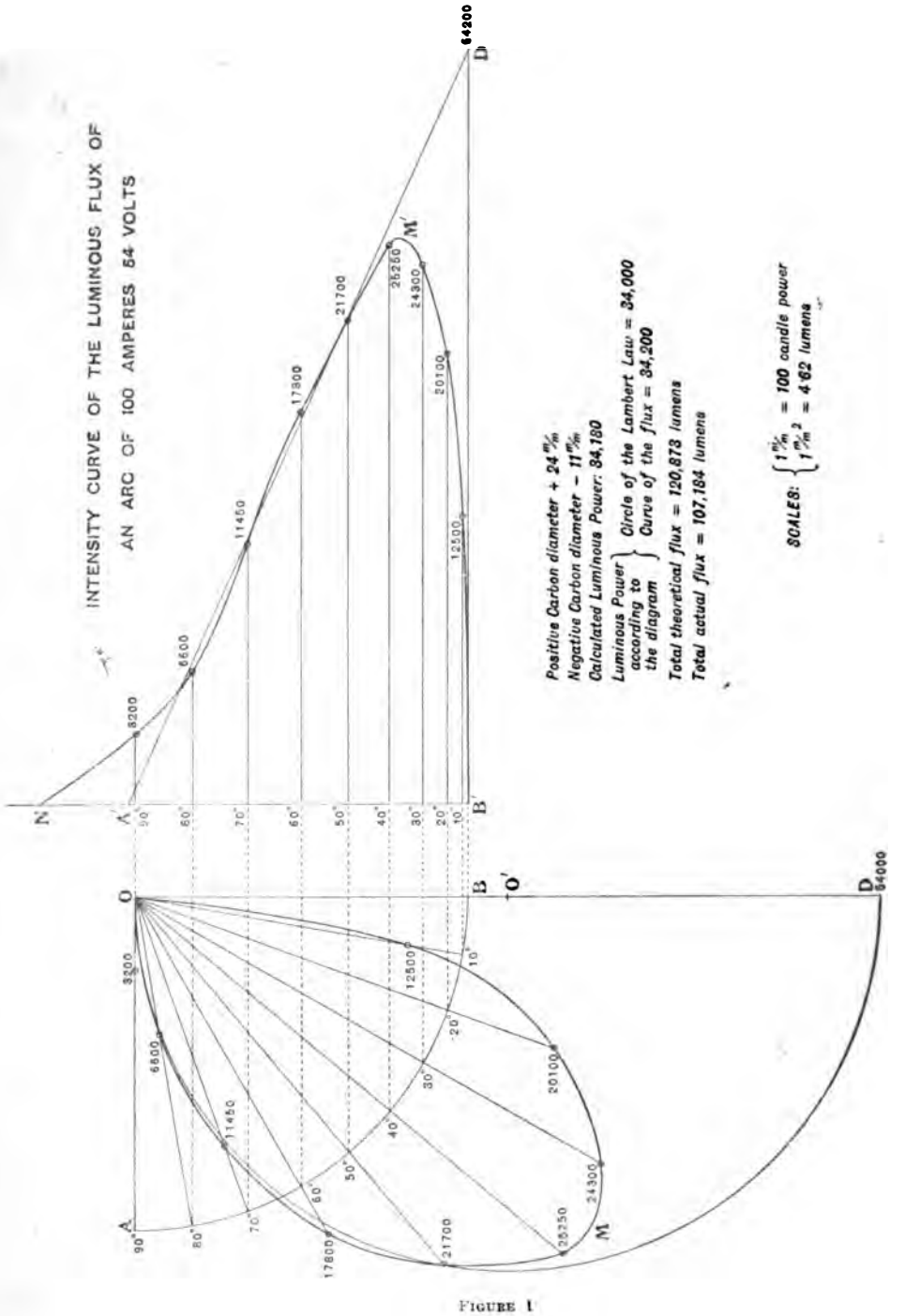

INTENSITY CURVE OF THE LUMINOUS FLUX OF
AN ARC OF 100 AMPERES 54 VOLTS
Positive Carbon diameter + 24 m/m
Negative Carbon diameter – 11 m/m
Calculated Luminous Power: 34,180
Luminous Power according to the diagram
Circle of the Lambert Law = 34,000
Curve of the flux = 34,200
Total theoretical flux = 120,873 lumens
Total actual flux = 107,184 lumens
SCALES: 1 m/m = 100 candle power
1 m/m² = 4·62 lumens

FIGURE 1

is not produced by the crater, but by the point of the negative carbon and, to a small extent, by the arc flame itself. We omitted this point as regards the intensity curve OM, which is carried through the origin O at the centre of the crater.

It is easy to see that the first part of the intensity curve, on the side of the straight line OA, and up to an angle of approximately 50°, calculated from OA, or at about 40°, calculated from the axis of the crater, is almost exactly at a tangent to a circle passing from the origin O, and having its centre at O′ on the straight line OB, that is to say the line of the axis of the carbons. In fact, if the negative were non-existent, the Lambert Law demands that the intensity curve shall be represented by a circle, with a diameter OBD.

It can therefore be seen that the influence of the negative is not felt until 50° from the axis of the carbons.

It is indicated at O′, on the straight line OB, the centre of the circle which would represent the theoretical emission of radiance according to the Lambert Law.

Calculation of the Luminous Flux.—In order to calculate the luminous flux, the well-known construction indicated by M. Rousseau is applied.

On a straight line A′B′, parallel to OB, the points of the reference circle are projected every 10°.

On each of the points projected, perpendicular straight lines A′B′ are drawn, and on these is shown the value of the intensity corresponding to that direction in space.

The working area thus obtained represents the luminous flux.

It will be noticed that, if it is a question of the theoretical intensity curve (the negative being supposed to be removed),

i.e., the circle OD, the corresponding working area of the luminous flux would be represented by a triangle, having as a base the projection OB and as elevation the maximum intensity given by the crater within the axis of the negative, supposing the negative to be removed.

The actual curve is to a great extent identical with a straight line in the curve A′M′. As the point D′ is not known *à priori*, it is easy to determine it on the diagram by crossing the straight line, which is exactly at a tangent to the curve A′M′, such as shown on the drawing.

It will be observed that we have caused the curve limiting the flux to pass as far as the point N on the straight line A′B′, taking into account the flux supplied by the point of the negative and the flame of the arc.

In reality, this amount of light, represented by the triangle having as a base A′N, is never utilised in searchlights, because the amplitude of the reflector never attains 180°, which angle would have to be exceeded in order to make use of this minimum portion of the flux.

Once the curve of the flux has been traced and is squared, it is found that the surface A′M′B′ represents a total flux of 107,184 lumens. The total theoretical flux Φ, supposing the negative to have been removed, that is to say the surface A′D′B′, would equal 120,873 lumens.

The ratio of these two quantities one to another represents a proportion of 88·7 per cent.

Ratio of the Practical Flux to the Theoretical Flux.—With the aid of this construction it is easy to measure the amount of real flux φ, which is emitted by the crater within a specified solid angle, for instance every 10°, and consequently to determine the value of the ratio of the real flux φ to the total theoretical flux Φ within a given angle.

The numbers thus determined are grouped in the following schedule :—

ARC OF 100 AMPERES AT 54 VOLTS.

	Lumens.	Ratio of the Practical Flux to the Theoretical Flux. Total. $K = \frac{\varphi}{\Phi}$. Per cent.
From 0° to 10°	1,524	1·26
20°	7,114	5·89
30°	18,560	15·35
40°	36,405	30·13
50°	56,364	46·60
60°	75,583	62·50
70°	92,030	76·20
80°	102,564	84·90
90°	107,184	88·70

By analysing the numerous experiments which we have made during recent years, we have found that when thick negatives are used, the ratio K of the real flux within a specified solid angle to the theoretical flux is lower than when negatives of a smaller diameter are used.

The following schedule shows the average values, which can be obtained with this ratio, for negatives having diameters in the proportion of 10 to 16 :—

	Ratio of the Practical Flux to the Theoretical Flux. $\frac{\varphi}{\Phi} = K$. Thick Negatives.	$\frac{\varphi}{\Phi} = K$. Small Negatives.
From 0° to 10°	0·0055	0·003
20°	0·04	0·04
30°	0·13	0·15
40°	0·26	0·29
50°	0·40	0·46
60°	0·56	0·62
70°	0·69	0·76
80°	0·79	0·86
90°	0·84	0·92

In the example of Fig. 1 it is seen that the proportion obtained is nearer the figures given in the last column, that is to say, those for arcs with small negatives.

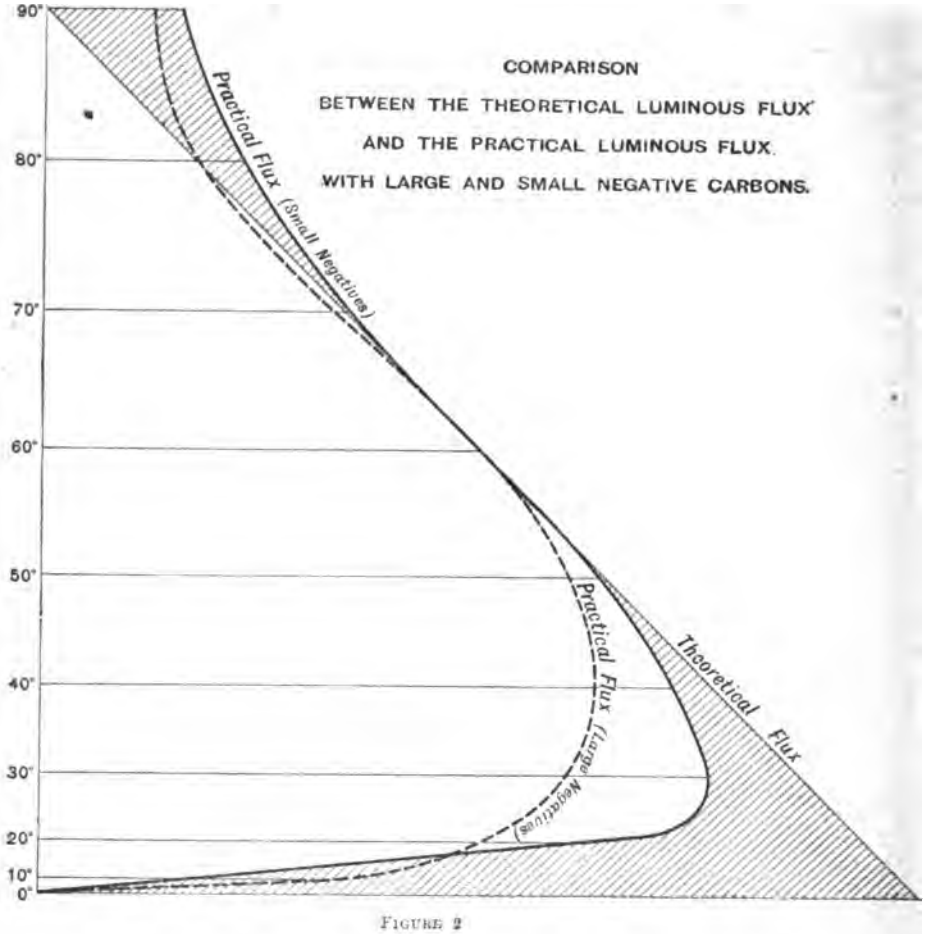


FIGURE 2

In Fig. 2 we have traced curves which make it possible to compare the theoretical luminous flux of a specified arc and the real flux supplied by that arc, either with a thick or a small negative, the working area of the curve giving the value of the flux for each solid angle.

From the diagram in Fig. 3 it is possible to instan-

taneously measure the value K of the ratio of the real flux to the theoretical flux for each solid angle of contact.

Fig. 4 shows the same diagram for a lamp with inclined

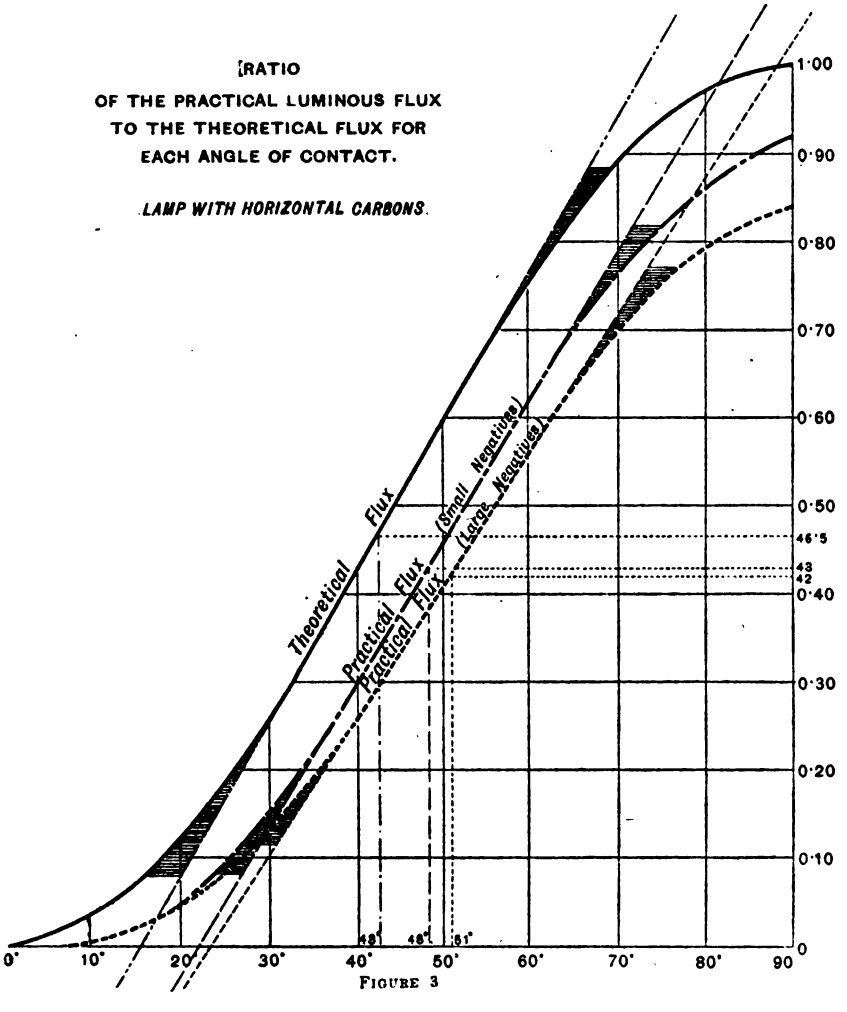


FIGURE 3

carbons, similar to those of numerous searchlights still in use in certain Navies.

These average results, which our numerous experiments have enabled us to determine, make it possible to calculate *à priori* for a specified arc and reflector the proportion of

the luminous flux received by the reflector, supposing the arc to have been placed at the focus of the mirror. According as to whether the arc has been obtained with a thick or a small negative, one or other of the schedules given

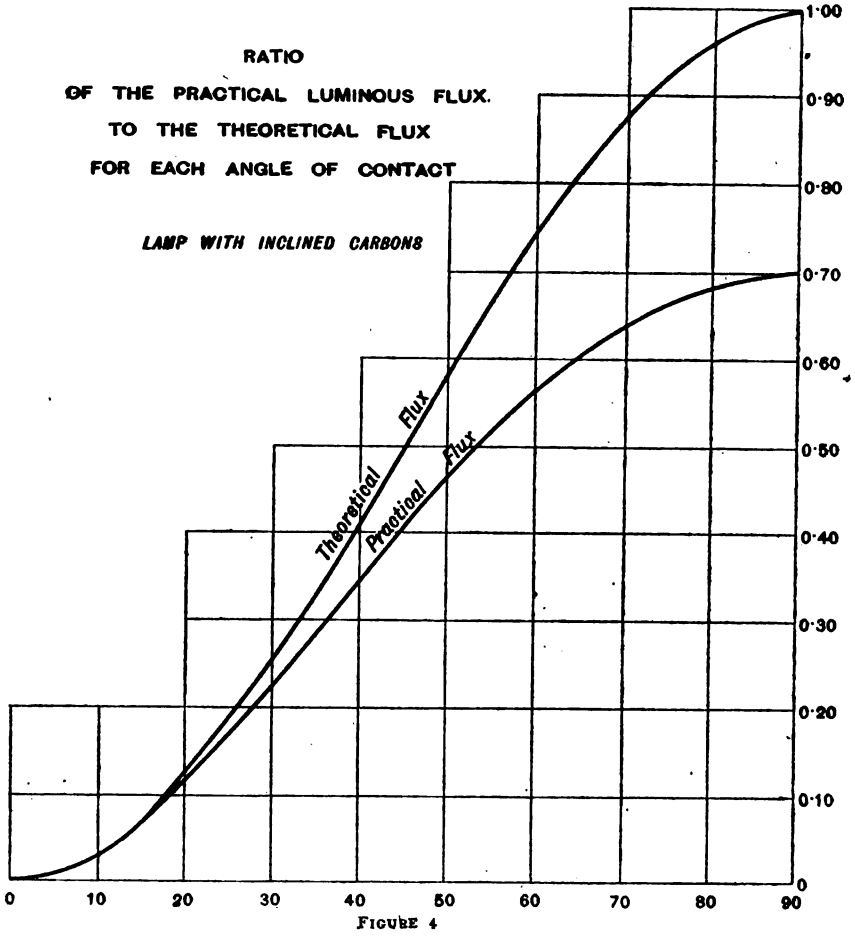


FIGURE 4

above must be applied, and also the diagram in Fig. 3. However, it is indispensable that, when dealing with an arc which does not come within the conditions of the experiments already carried out, one should be able to calculate the total theoretical flux, which would be

supplied by this arc, the negative being assumed to be removed.

The diagrams, such as those in Fig. 1, make it possible to determine the maximum intensity supplied by the crater within the axis itself of the carbons, supposing the negative to have been removed.

If we take

S to be the total working area of light of the crater,

e, the average intrinsic brilliancy of the crater,

the illuminating power or luminous intensity of the crater is represented by the value $P = Se$.

The total theoretical flux Φ emitted by that crater is shown by the proportion $\Phi = \pi Se$, which is nothing but the expression of the ratio of a body which follows the Lambert Law.

The diagram in Fig. 1 enables the maximum intensity of the crater to be determined (that is to say the value Se) by the aid of the tangent to the radiance curve, which shows the position of the point D′, and it will be seen that it is possible by measuring the straight line B′D′ to determine the value of the maximum theoretical intensity.

It is therefore possible to measure the total theoretical flux of a specified arc, provided one has measured its curve of intensity.

By making this calculation on a large number of experimental curves, we have ascertained that the total flux of an electric arc is a direct ratio to the electrical energy absorbed at the terminals of the arc, that is to say, to the product of the intensity in amperes and the electromotive force at the terminals of the arc in volts.

PROPORTION BETWEEN THE TOTAL THEORETICAL FLUX AND THE ELECTRICAL ENERGY.—*Arcs of* 0 *to* 40 *Amperes.*—For small searchlight arcs from 0 to 40 amperes, we have

ascertained that the maximum luminous power of the crater was connected by the following proportion to the electrical energy absorbed by the arc, for a current density varying between 0·10 amperes and 0·20 amperes per square millimetre :—

$$P = 6{\cdot}28\ W - 700 \tag{1}$$

It is easy to deduce from this proportion the value of the maximum theoretical radiance in lumens, as shown by the following proportion :—

$$\Phi = \pi P = 19{\cdot}75\ W - 2{,}200 \tag{2}$$

Arcs of 50 *to* 250 *Amperes.*—For more powerful arcs, the proportion becomes modified and is as follows, for a current density varying from 0·13 amperes to 0·15 amperes per square millimetre :—

For the maximum luminous power,

$$P = 5{\cdot}75\ W + 3{,}100 \tag{3}$$

For the maximum radiance in lumens,

$$\Phi = 18{\cdot}06\ W + 9{,}740 \tag{4}$$

It is therefore easy, with the aid of these proportions and knowing the power absorbed by the arc, to determine its maximum intensity, or its total theoretical flux.

Once the flux has been ascertained, the schedules and diagrams already given make it possible to immediately deduce the practical flux for any given solid angle in contact with the reflector.

The empirical relations, which we have just set out, exactly reproduce the results of our experiments, allowing for errors which do not exceed 2·5 to 3 per cent. In practice therefore they may always be taken as examples.

EFFICIENCY OF AN ELECTRIC ARC.—We call efficiency of an electric arc, the ratio of the total theoretical flux to the energy absorbed by the arc.

This definition leads to the proportion $\rho = \frac{\Phi}{W}$

If therefore the values given in the formulæ (2) and (4) are applied, it is easy to calculate the watt efficiency which is represented by a specified numerical value in lumens.

For arcs up to 40 amperes,

$$\rho = 19{\cdot}75 - \frac{2{,}200}{W} \tag{5}$$

For arcs exceeding 50 amperes,

$$\rho = 18{\cdot}06 + \frac{9{,}740}{W} \tag{6}$$

Let us apply this conception of efficiency to small arcs. Taking for instance, an arc of 20 amperes at 45 volts at the terminals.

According to formula (5), its efficiency $\rho = 17{\cdot}31$.

For an arc of 40 amperes at 46 volts, the efficiency ρ would be 18·56.

Therefore by going from 20 to 40 amperes, it is seen that the efficiency has increased in the ratio of these two numbers, namely by approximately 7 per cent.

If we undertake the same investigation for large arcs, working at a high voltage, we obtain the following results:—

For 50 amperes, 60 volts, $\rho = 21{\cdot}31$
„ 100 „ 68 „ $\rho = 19{\cdot}49$
„ 150 „ 75 „ $\rho = 18{\cdot}93$
„ 250 „ 80 „ $\rho = 18{\cdot}55$

Passing from 50 to 100 amperes, the efficiency therefore decreases by 8·5 per cent.

Passing from 50 to 150 amperes, the efficiency decreases by 11 per cent.

Finally, passing from 50 to 250 amperes, where the number of amperes is five times greater, the efficiency decreases by 13 per cent.

It is therefore seen that for small arcs the efficiency slightly increases with the intensity, whereas for large arcs it decreases, but not to any considerable extent.

This may be explained with regard to the large arcs, by the fact that it is far more difficult in carbons of a large diameter to obtain a quality equal to that of carbons of smaller diameter. In fact, it is known that the preparation and baking of positive carbons of large diameters is a far more delicate undertaking than for smaller carbons. Moreover, in the case of large arcs, the formation of the crater is less regular, because part of its surface (by no means negligible) is hidden by the edges and by the indentations they present. It is therefore not surprising that in large arcs the luminous output decreases with the intensity, whereas in the case of small arcs, up to 40 amperes, it has a tendency to increase.

Illuminating Surface of the Crater.—The working area of the lighting surface of the crater varies with the intensity of the current and the diameter of the positive.

The empirical law, which we have been able to establish, results from the following considerations :—

We have first of all tried to ascertain whether the diameter of the negative exerted any kind of action on the working surface of the lighting crater, the diameter of the positive carbon remaining the same.

We have therefore undertaken a series of experiments on different diameters of positives, each successively burning with a series of negatives in decreasing diameters.

We have tested the following diameters for positives: 30, 28, 26, 24, and 22 millimetres, each one in turn with negatives of 21, 13, 12, 11, and 9 millimetres.

We have also had a series of positives 24, 22, and 19 millimetres burning with negatives of 16, 11, and 9 millimetres.

The total of these thirty-four series of tests, duly controlled, proved that the diameter of the crater remained unchanged for the same positive diameter and the same intensity, regardless of the diameter of the negative. In fact, the average errors in these measurements have not exceeded 3·8 per cent., a variation which falls well within the range of observation errors.

By comparing the dimensions of craters, obtained with the same intensity of current and the same negative, but with a different series of positives, we have ascertained that the diameter of the crater varies with the diameter of the positive carbon in proportion to the square root of the diameter. The total of the errors gives an average of 1·6 per cent.

Finally, by comparing the diameters of the craters having the same pair of carbons, but with a varying intensity of current, it was found that the diameter of the crater varied in proportion to the square root of the current.

The empirical law which results from these observations, and which connects the diameter δ of the crater to the diameter D of the positive and to the intensity I, is given by the following proportion :—

$$\delta = a\sqrt{DI} \tag{7}$$

in which a is a constant.

A general verification of this law became imperative, and it was carried out on arcs the intensity of which varied from 6 to 200 amperes, with positive carbon diameters

measuring from 6 to 44 millimetres. We thus recognised that the constant a of the preceding formula was really represented by the value 0·344, the diameter of the crater being given in millimetres, as is also the diameter D of the positive; the intensity of the current being given in amperes or

$$\delta = 0{\cdot}344 \sqrt{\mathrm{DI}} \tag{7}$$

From this formula it is possible to calculate the working surface of the crater, which is as a rule a circle, and is represented by

$$\mathrm{S} = 0{\cdot}093\ \mathrm{DI} \tag{8}$$

Observations carried out more than twenty years ago on the craters of electric arcs agree with the formula (7) to within 2 to 3 per cent., which may be considered to be perfectly satisfactory.

General Proportion defining the Luminous Power of an Electric Arc.—If the law which gives the working area of a crater is compared with the empirical law previously mentioned for the value of the maximum intensity P or the luminous flux Φ, a general proportion may be established between the average intrinsic brilliancy of the crater, the diameter of the positive, the intensity of the current, and the voltage at the terminals. It must, however, not be forgotten that the value of the total luminous flux does not depend on the intrinsic brilliancy, but that it is a function of the electrical energy W absorbed by the arc.

As a matter of fact, we have found that, as a rule,

$$\Phi = \pi \mathrm{S} e = m\mathrm{W} + n \tag{4}$$

and, on the other hand,

$$\mathrm{S} = b\mathrm{DI}, \text{ or } b = \frac{\pi}{4} a^2$$

from which results

$$\mathrm{DI}e = \frac{m}{\pi b}\mathrm{W} + \frac{n}{\pi b} = \frac{m}{\pi b}\mathrm{EI} + \frac{n}{\pi b}$$

or

$$e\mathrm{DI} = \alpha\mathrm{EI} + \beta \tag{9}$$

The general formula thus set out has four variables.

From it can be deduced the value of the intrinsic brilliancy by the proportion :

$$e = \alpha\frac{\mathrm{E}}{\mathrm{D}} + \frac{\beta}{\mathrm{DI}} \tag{10}$$

It is therefore clear how complex is the conception of the intrinsic brilliancy, seeing that it depends, at one and the same time, on the diameter of the positive carbon, the intensity of current, and the voltage.

The empirical proportions indicated, which are merely the results of observations, prove that the intrinsic brilliancy decreases with the increase of the current intensity and of the diameter of the carbons used in practice. The experience which has made it possible to determine the diameters used for the entire series of searchlights, from a projector mirror of 30 centimetres to one of 2 metres, proves that the intrinsic brilliancy of the crater decreases, passing from the small arcs to the large arcs (density from 0·13 ampere to 0·15 ampere per square millimetre for low voltage carbons, 0·21 ampere to 0·22 ampere per square millimetre for high voltage carbons). Owing to the series of carbons having been arranged to be operated at the same current density or with slight variations, it may be said that for a given current density the intrinsic brilliancy decreases with the intensity, when increasing the size of the projectors. At first sight it seems difficult to explain this ; but it is apparently due to the defects in the manufacture of carbons of large diameters. For instance, in large arcs

of more than 130 amperes it is very difficult to obtain steady burning ; the arc frequently begins to hiss, it wanders round the carbon and the crater becomes deeply hollowed, probably owing to an inferior core, which becomes decidedly more pronounced in the case of large diameter carbons.

Many years ago M. Blondel proved that as soon as an arc begins to hiss its luminous intensity decreases to a considerable extent. The average of the photometrical tests given in the preceding formulæ takes into account these defects in arcs of high intensities.

If it were possible to give a greater stability to large arcs and to obtain more shallow and less irregular craters, either by modifying the composition of the core or of the carbon or by some outside physical action, it is certain that, instead of diminishing with the increase in the carbon diameter and the current density, the intrinsic brilliancy would remain unchanged or would even increase.

From this it will be apparent that there is opportunity for considerable improvement in the burning of large arcs, which would lead to the more frequent use of large searchlights.

The empirical law (previously referred to) gives the following values for small arcs, up to 40 amperes :—

$$\alpha = 67{\cdot}6 \qquad \beta = -7{,}500$$

The formula having three variables is therefore numerically as follows,

$$(11) \qquad e\mathrm{DI} = 67{\cdot}6\ \mathrm{EI} - 7{,}500$$

For large arcs, from 50 to 150 amperes, the values of the coefficients are the following :—

$$\alpha = 61{\cdot}8 \qquad \beta = 33{,}300$$

The formula is therefore as follows,

$$(12) \qquad e\mathrm{DI} = 61{\cdot}8\ \mathrm{EI} + 33{,}300$$

CHAPTER II

THEORETICAL ILLUMINATION OBTAINED WITH A SPECIFIED REFLECTOR

CALCULATION OF THE FLUX OBTAINED WITH A GIVEN SIZE OF REFLECTOR.—With the assistance of the empirical rules previously given, which practically represent the average of a very large number of experiments, it is possible to calculate the luminous flux φ which falls on a reflector of known dimensions. The results of these calculations have been summarised in Tables I. and II.

We have taken as a basis a series of reflectors having diameters varying from 0·30 metre to 2 metres, and we have indicated for each diameter of reflector the values of the luminous flux corresponding to three different focal lengths. The first is the shortest and equals one third of the reflector diameter, the second is equal to 40 per cent. of the diameter, and the third 60 per cent. of the diameter.

We have made these calculations, firstly, for a series of low voltage arcs, and, secondly, for a series of high voltage arcs. The numerous experiments have clearly shown to what extent the voltage increases the luminous flux received by any given reflector. The only objection to the use of high voltages is that it necessitates the use of carbons of special construction and quality and difficult to obtain. The combustion is more rapid and entails more frequent renewals unless some special device, such as the glimmer light, is employed.

AVERAGE THEORETICAL ILLUMINATION.—We term the average theoretical illumination to be the zone in contact

with the beam of light from a searchlight at a specified distance l, assuming the efficiency of the reflector to equal unity, that is to say, by supposing that it reflects without any loss whatever the whole of the luminous flux it receives, and that the atmospheric transparency is perfect, so that no fraction of the flux becomes absorbed during the projection of the beam of light.

The calculation of the average illumination is based on the supposition that the luminous flux is distributed in a uniform manner throughout the whole extent of the reflected beam of light.

In M. Blondel's book on the "Theory of Searchlights," published in 1894, it is emphasised that when the source of light is placed at the focus of a perfect reflector, the lighting of the right section of the beam of light is composed of a central zone, which is uniformly lighted at a maximum intensity, and of a marginal zone, in which the lighting decreases from the centre to the outer periphery.

This method of considering the illumination from a searchlight is absolutely correct from a theoretical point of view, and gives good results for searchlights having a long focus, which were the only ones in use some twenty years ago. With searchlights having a short focal length it is necessary to allow for the average total flux. The observer who is operating the searchlight endeavours to obtain a beam of uniform illumination, and adjusts the lamp until it is ascertained that the section is uniformly illuminated and the maximum visibility obtained.

One may therefore, without any appreciable error, consider the illumination of a beam of light as an average illumination, the whole of the reflected flux being uniformly distributed over the working area of the zone illuminated.

With searchlights having a short focal length, the average illumination thus calculated is less than the maximum

at the axis of the beam of light obtained by placing the source of light at the focus. The average illumination, however, always remains in proportion to the maximum illumination at the axis.

CALCULATION OF THE FLUX ANGLE UTILISED BY THE REFLECTOR.—If we call Δ the diameter of the parabolic reflector and f its focal length, it may be assumed that :—

$$\Delta = 2\mu f \qquad \text{or} \qquad y = \mu f$$

y being the half-diameter of the reflector and μ a coefficient to be determined.

If we now call 2σ the total flux angle in contact with the reflector, the equation of the parabola gives us

$$y^2 = 4fx \qquad \text{and} \qquad y = (f - x)\ tg\sigma$$
$$x = \frac{y^2}{4f}$$

from which is obtained

$$x = \frac{\mu^2 f^2}{4f} = \frac{\mu^2 f}{4} \qquad f - x = f\left(1 - \frac{\mu^2}{4}\right)$$

this gives finally

$$\mu f = f\left(1 - \frac{\mu^2}{4}\right) tg\sigma$$

and

$$tg\sigma = \frac{4\mu}{4 - \mu^2} \tag{13}$$

This formula therefore enables us, for a specified focal length, to calculate the flux angle utilised by the reflector.

In the following tables we have assumed three different focal lengths :—

1°

$$\Delta = 3f \qquad f = \frac{\Delta}{3}$$

or

$$2y = 3f \qquad y = 1{\cdot}5f$$
$$\mu = 1{\cdot}5$$

The focal length is then one third of the reflector diameter. Thus :—

$$tg\sigma = \frac{6}{1{\cdot}75} \qquad \sigma = 73°44'{\cdot}4$$
$$2\sigma = 147°28'{\cdot}8$$

2°

$$\Delta = 2{\cdot}5f \qquad f = 0{\cdot}40\Delta$$
$$y = 1{\cdot}25f \qquad \mu = 1{\cdot}25$$
$$tg\sigma = \frac{5{\cdot}00}{2{\cdot}4375}$$

thereby giving a utilised flux angle of

$$\sigma = 64°$$
$$2\sigma = 128°$$

In this second hypothesis the focal length equals 40 per cent. of the diameter.

3°

$$\Delta = 1{\cdot}666f \qquad 2y = \frac{5}{3}f \qquad y = \frac{5}{6}f$$
$$\mu = \frac{5}{6}$$

Deduced from this

$$tg\sigma = \frac{120}{119}$$

which gives as the utilised flux angle

$$\sigma = 45°14'{\cdot}4$$
$$2\sigma = 90°28'{\cdot}8$$

In this last hypothesis the focal length equals 60 per cent. of the mirror diameter.

If we now refer to Fig. 3, which shows, for lamps with horizontal carbons, the ratio of the practical luminous flux φ to the theoretical flux Φ in respect of each angle of contact, it will be possible to calculate either for a low voltage arc having a large negative, or for a high voltage arc having a small negative, the ratio of the utilised flux to the theoretical flux for each of the three focal lengths previously referred to.

A summary of the result of this calculation is as follows :—

	Values of $K = \frac{\varphi}{\Phi}$		
	$f = \frac{\Delta}{3}$ $\mu = 1{\cdot}50.$	$f = 0{\cdot}40\Delta$ $\mu = 1{\cdot}25.$	$f = 0{\cdot}60\Delta$ $\mu = \frac{5}{6}.$
Large negatives. Low voltage.	0·7375	0·6175	0·884
Small negatives. High voltage	0·8075	0·685	0·8825

General Formula showing the Average Theoretical Illumination.—From the above considerations it becomes possible to calculate the average illumination ϵ, at a specified distance l, for a reflector of given diameter and focal length, the efficiency of which is assumed to be equal to unity. If ϵ is the average illumination at a distance l,

d the diameter of the lighted zone at a distance l from the reflector,

φ the light flux falling on to the reflector,

δ the diameter of the crater,

then

$$\frac{d}{l} = \frac{\delta}{f} \qquad d = l\frac{\delta}{f} \tag{14}$$

from which is deduced :

$$\frac{\pi d^2}{4} = \frac{\pi}{4} l^2 \frac{\delta^2}{f^2}$$

But as

$$\epsilon_1 = \frac{\varphi}{\frac{\pi}{4} l^2 \frac{\delta^2}{f^2}} = \frac{4}{\pi} \varphi \frac{1 f^2}{l^2 \delta^2}$$

$$\epsilon_1 = 1{\cdot}273 \, \varphi \frac{1 f^2}{l^2 \delta^2} \tag{15}$$

Assuming the distance l to be equal to 1,000 metres, the following formula will result :—

$$\epsilon_{1000} = 1{\cdot}273 \, \varphi \frac{f^2}{\delta^2} \frac{1}{10^6} \tag{16}$$

In this formula the flux φ is given in lumens. The ratio of the focal length $\frac{f}{\delta}$ to the diameter of the crater must be given in the same units of measurement.

With the aid of this formula, we have calculated the values given in the three last columns of Tables I. and II.

We would again mention that these theoretical values of the illumination at a distance of 1,000 metres do not take into account either the efficiency of the reflector or the absorption due to the atmosphere. We shall point out later how they are to be corrected, but without correction the values are highly instructive and show the rapid increase of the illumination with the diameter. They also clearly explain the influence exerted by the focal length on the illumination.

The value of the average illumination increases when changing from a very short focal length equal to a third of the mirror diameter, to a relatively long focal length,

TABLE I.—TEST RESULTS AT LOW VOLTAGE AND WITH LARGE NEGATIVE CARBONS.

Diameter of Mirror in Metres.	Power Consumption.		Diameter of Positive Carbon in m/m.	Diameter of Crater in m/m.	Area of Crater in m/m².	Average Specific Brilliancy in Candle-power per m/m².	Theoretical Flux in Lumens.	Average Theoretical Illumination at a distance of 1,000 metres, e 1,000.		
	Amperes.	Volts.						$\Delta = 3f$	$\Delta = 2{\cdot}5f$	$\Delta = 1{\cdot}666f$
Δ	I	E	D	δ	s	e	Φ	Lux.	Lux.	Lux.
0·30	12	44	14	4·5	15·62	168	8,240	3,825	4,600	5,610
0·40	25	46	20	7·7	46·5	141	20,500	5,780	6,960	8,480
0·50	50	47	22	11·4	102·5	162	52,190	10,480	12,650	15,370
0·60	60	48	23	12·8	128·3	153	61,740	14,140	17,030	20,780
0·75	70	49	25	14·4	163	140	71,740	20,350	24,480	29,820
0·90	90	50	28	17·3	234	124	91,040	25,710	31,400	37,720
1·10	100	51	30	18·8	279	116	101,840	29,660	43,900	53,400
1·20	110	52	32	20·4	327	110	113,140	40,900	49,300	59,900
1·50	150	56	38	26	530	97	161,340	56,050	67,500	82,350
2·00	150	56	38	26	530	97	161,340	99,400	120,000	146,300

TABLE II.—TEST RESULTS AT HIGH VOLTAGE AND WITH SMALL NEGATIVE CARBONS.

Diameter of Mirror in Metres.	Power Consumption.		Diameter of Positive Carbon in m/m.	Diameter of Crater in m/m.	Area of Crater in m/m².	Average Specific Brilliancy in Candle-power per m/m².	Theoretical Flux in Lumens.	Average Theoretical Illumination at a distance of 1,000 metres, ϵ 1,000.		
	Amperes.	Volts.						$\Delta = 3f$	$\Delta = 2{\cdot}5f$	$\Delta = 1{\cdot}666f$
Δ	I	E	D	δ	s	e	Φ	Lux.	Lux.	Lux.
0·30	25	55	12	6	27·9	285	25,000	7,125	8,750	10,940
0·40	40	58	15	8·4	55·8	249	43,700	11,320	13,840	17,350
0·50	60	62	19	11·6	106	231	76,940	16,280	19,920	25,020
0·60	70	65	20	12·9	130	225	91,940	22,670	27,740	34,900
0·75	80	66	22	14·4	164	204	105,140	32,620	39,800	50,000
0·90	110	69	25	18	256	183	146,740	43,320	51,250	64,330
1·10	130	72	28	20·8	339	169	178,840	57,000	69,900	88,000
1·20	150	75	30	23·1	418	162	212,940	65,650	80,000	98,000
1·50	175	77	32	25·7	521	154	252,940	98,300	120,000	150,900
2·00	200	78	35	28·8	651	143	291,540	160,400	195,800	247,000

equal to 60 per cent. of the diameter. It may be asked whether this increase would continue if the focal length were further increased.

A fairly simple calculation shows that there exists a focal length which corresponds to the average illumination.

MAXIMUM OF THE AVERAGE THEORETICAL ILLUMINATION. —If reference is made to formula (15), showing the average illumination at a distance l from the searchlight, it will be seen that, for the same diameter of reflector and the same arc, the value of the average illumination varies with the product

$$\varphi f^2$$

This product may be expressed in another way, by introducing the angle of the utilised flux 2σ.

In effect, one has

$$\Delta = 2\mu f \qquad \text{and} \qquad tg\sigma = \frac{4\mu}{4 - \mu^2}$$

from which is deduced

$$\mu = \left\{\frac{\sqrt{1 + tg^2\sigma} - 1}{tg\sigma}\right\}$$

or

$$\mu = 2\,\frac{1 - \cos\sigma}{\sin\sigma}$$

or

$$\Delta = 4\,\frac{1 - \cos\sigma}{\sin\sigma} f \qquad f = \frac{\Delta}{4}\,\frac{\sin\sigma}{1 - \cos\sigma}$$

By combining this formula of the focal length to the formula for the illumination the following general formula is obtained :—

$$\epsilon = 1{\cdot}273\,\frac{I}{\delta^2 l^2}\,\varphi\,\frac{\Delta^2}{16}\left(\frac{\sin\sigma}{1 - \cos\sigma}\right)^2$$

It is therefore seen that, in this expression, when the

focal length is made to vary, the only expression which varies is

$$\varphi \left(\frac{\sin \sigma}{1 - \cos \sigma}\right)^2 = K\Phi \left(\frac{\sin \sigma}{1 - \cos \sigma}\right)^2$$

It is easy to calculate the value of this product, as the curves of Fig. 2 provide for each value of the angle σ, the value of the ratio K of the utilised flux φ corresponding to the theoretical flux Φ.

From the above, it is possible to draw up the following table, in which is shown both for arcs with large negatives and low voltage and also for arcs with small negatives and high voltage, the value of the product :—

$$K = \left(\frac{\sin \sigma}{1 - \cos \sigma}\right)^2$$

TABLE III.

Value of σ	Value of the Product $K \left(\frac{\sin \sigma}{1 - \cos \sigma}\right)^2$.	
	Large Negatives, Low Voltage.	Small Negatives, High Voltage.
Degrees.		
10	0·171	0·652
20	1·256	1·449
30	1·807	1·933
38	1·953	2·189
40	1·958	2·200
42	1·945	2·203
45	1·920	2·182
50	1·840	2·100
55	1·775	1·975
60	1·680	1·845
70	1·407	1·560

If the figures in the second column of Table III. are examined, it will be found that for low voltage arcs the maximum of the product, that is to say of the illumination, is given by the total flux angle.

$$2\sigma = 80°$$

This angle corresponds to a focal length equal to 0·687 of the mirror diameter.

For high voltage arcs the half-angle of the utilised flux σ, corresponding to the maximum illumination, is approximately 42°, or 84° for the whole angle. This value of σ corresponds to a value of the focal length equal to 0·664 of the mirror diameter.

In modern searchlights the focal length is generally below that which would correspond to the maximum illumination.

In the case of large projectors it is necessary to mind that, if the focal length is increased until the indicated limit is reached, the result will be that the diameter of the beam of light will be reduced too much and the beam will no longer illuminate a sufficiently extensive field. As a rule the value of the focal length is generally between 40 and 50 per cent. of the mirror diameter.

The German firm of Schukert some twenty years ago originated the idea of projectors having short focal lengths. The various articles written by the engineers of this firm were freely distributed to the military experts of the whole world and contained many erroneous theories, one of which was that the illumination would gradually increase as the focal length is reduced. The Germans, however, have since given up the use of searchlights with short focal lengths equal to one third of the mirror diameter and even less and in their present construction they employ a focal length equal to 40 per cent. of the mirror diameter.

It is not inexpedient to state that Colonel Mangin for more than twenty years used in his celebrated mirrors a focal length of about 70 per cent. of the diameter.

Width of the Illuminated Zone.—By referring to

Tables I. and II., and with the aid of formula (14), it is easy to calculate the total width of the zone illuminated for various sizes of searchlights and focal lengths, with due consideration to the area of the positive carbon crater.

In Table IV. these values are given, assuming the observer to be situated at a distance of 1,000 metres from the searchlight. In practice, when the atmospheric transparency is

TABLE IV.

Diameter of the Mirror.	Diameter of the Zone Illuminated at 1,000 metres from the Searchlight.					
	Low Voltage.			High Voltage.		
	$\Delta = 3f$.	$\Delta = 2{\cdot}5f$.	$\Delta = 1{\cdot}666f$.	$\Delta = 3f$.	$\Delta = 2{\cdot}5f$.	$\Delta = 1{\cdot}666f$.
Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.
0·30	45·00	37·50	25·00	60·00	50·00	33·33
0·40	57·70	48·10	32·10	68·00	52·50	35·00
0·50	68·40	57·00	38·00	69·60	58·00	38·70
0·60	64·00	53·33	35·55	64·50	53·80	35·90
0·75	57·60	48·00	32·00	57·60	48·00	32·00
0·90	57·66	48·10	32·00	60·00	50·00	33·33
1·10	51·30	42·70	28·50	56·80	47·30	31·50
1·20	51·00	42·50	28·35	57·80	48·10	32·10
1·50	52·00	43·33	28·88	51·40	42·80	28·50
2·00	39·00	32·50	21·67	43·20	36·00	24·00

small, the width of the illuminated zone at the limit of the range is somewhat reduced, that is to say, the eye which observes the illuminated field appears to be smaller than it actually is. On the other hand, in the immediate vicinity of the searchlight, say up to a distance of 500 to 600 metres, the diameter of the zone illuminated is greater than that indicated by theory, owing to the auxiliary or parasitic luminous flux from the negative carbon and the arc flame which the atmospheric absorption causes to disappear at a short distance.

CHAPTER III

EFFICIENCY OF ELECTRIC SEARCHLIGHTS

THE efficiency of an electric arc searchlight may be strictly defined as being the ratio of the luminous flux, projected at a distance by the apparatus, to the luminous flux emitted by the electric arc and received by the reflector.

The difference between these two luminous fluxes represents the actual losses of the apparatus; these losses are of various kinds:—

The first is due to the reflector itself, which absorbs a certain quantity of the incident flux received, for which the angle of reflection is consequently never equal to unity. There are, however, other losses caused by the inevitable shadows due to the lamp itself and to the plain front glass door of the searchlight, and, finally, to the flashing or signalling shutters in those searchlights provided with this device.

The sum of these individual losses makes up the total loss, and in order therefore to ascertain the total luminous efficiency it is necessary to find the product of the efficiencies of the various parts of the projector.

EFFICIENCY OF THE REFLECTING MIRROR.—The mirrors used in electric searchlights are of two kinds, *i.e.*, mirrors of silvered glass and gilded metal mirrors.

The mirrors of silvered glass are either of the Mangin or of the parabolic type. The gilded metal mirrors are paraboloids of revolution cut from a single surface.

Briefly, the term "efficiency" of a reflecting mirror is

the expression of the ratio of the reflected flux to the incident flux.

In Chapter I. was shown the method of calculating the flux emitted by an electric arc within a specified solid angle. With the help of the empirical law set forth, it is easy to calculate the amount of luminous flux caught by a given reflector from an electric arc of specified dimensions and powers.

The reflective power of the mirror must now be determined, and for this we have made use of two methods.

The first is based on the use of an apparatus termed a "reflectometer," which makes it possible to measure the power of reflection at any given point on the mirror. For this purpose a source of light as constant as possible, such as for instance an electric incandescent lamp, is placed before the reflector. The reflectometer, on the one hand, receives on a ground glass plate the rays reflected by the mirror, and on the other hand, on another identical plate, the direct rays coming from the source of light. The incandescent lamp must be adjusted until the intensities of the two illuminated areas are equalised. The efficiency is directly obtained from a graduated scale. The adjustment of the electric lamp brings it nearer to the reflector and shortens the path followed by the reflected rays, but lengthens the path traversed by the direct rays. This method is fairly accurate, and it enables an expert observer to determine the reflective power of a mirror to within 1 per cent.

The second method, due to M. Blondel, consists in lighting the mirror by means of an electric arc placed at its focus. The luminous flux reflected is caught on a sheet of paper at the front of the searchlight barrel and a photometer is placed at a known distance from the sheet of paper. The photometric intensity of the illuminated

disc is then measured, as if it were a primary luminous source.

In a second experiment the light rays from the electric arc are directed on to the sheet of paper, enclosing them in such a manner as to preserve the same solid angle for the luminous flux. The luminous intensity of the disc is measured as in the first experiment.

The ratio of the first measurement to the second gives the efficiency of the reflecting mirror.

These two methods, which have been applied to gilded metal mirrors as well as to parabolic mirrors of silvered glass and to glass mirrors of the Mangin type, have given results which are entirely in agreement. An average value for the power of reflection of a gilded mirror may be said to be 85 per cent.

A parabolic mirror of silvered glass, the thickness of which does not exceed 10 millimetres, has a reflective power of 87 to 88 per cent. In order to obtain these results, however, the silvering must be in a perfect state of preservation, which may not be the case after a certain period of working.

As regards the Mangin mirror, the thickness of the glass at the edges tends to slightly decrease the efficiency, which for mirrors of short focal length does not exceed on an average 83 to 84 per cent.

As a general rule, it is not unusual to calculate on a power of reflection of 85 per cent. for a mirror in good condition.

Calculation of the Efficiency.—It is not impossible *à priori* to calculate the efficiency of a reflector, but considerable care is required, and also it is necessary to be acquainted with several coefficients.

As regards gilded metal mirrors, the metallic reflection

on the gold varies with the different wave lengths. Thus, various physicists have found that, for a wave length of 450, corresponding to extreme violet, the power of reflection falls to 37 per cent., and for dark red with a wave length of 700 it increases to 92·3 per cent.

By taking the wave length which corresponds to yellow, *i.e.*, about 600, it is found that the power of reflection is between 85 and 86 per cent. For a wave length of 650 it increases to 88 per cent.

It is therefore not surprising that the value of 88 per cent., which has been proved by practical tests, closely agrees with the average of the reflective power for the various wave lengths of the different sections of the spectrum of an electric arc and also considering the distribution of their intensities.

In the case of silvered glass mirrors the calculation is more intricate. At each of its points one may liken a reflector of silvered glass to a plane mirror having parallel faces and silvered on the back one.

If we call

r the coefficient of crystalline reflection, which Fresnel makes use of in his calculations,

τ the coefficient of the metallic reflection of silver on glass,

a the coefficient of transparency of glass per centimetre, that is to say, the proportion of light which passes through each centimetre of glass,

e the thickness of the glass,

the general formula which gives the efficiency of a silvered glass mirror is :

$$\varphi = r + \frac{\tau\,[(1 - r)\,a^e]^2}{1 - r\tau\,(a^e)^2} \qquad (17)$$

This formula assumes that the rays reflected at the

penetrating surface of the glass are exactly utilised in the beam of light.

Such a condition is not as a rule fulfilled, and only partially so in parabolic glass mirrors. In effect, a different curvature is required for the penetrating surface and for the reflecting surface of the reflector. In the event of none of these reflected rays, owing to their divergence, being utilised in the beam of light, the term r of the second item of the formula would disappear. In the event of only part of these rays being utilised, there would remain in the second item of the formula only a corresponding part of the term r.

The coefficient of crystalline reflection made use of by Fresnel, or the Fresnel coefficient, varies, as is well known, with the incidence. However, up to an angle of 30°, this variation is very slight, and it may be admitted that this coefficient has a value of 0° to 30° of incidence.

$$r = 0{\cdot}045$$

The loss by reflection at the passage of each crystalline surface is therefore approximately 4·5 per cent.

Numerous tests have been carried out to determine the coefficient a, relating to the transparency of the glass used in reflecting mirrors, and the mean of the resultant tests show that

$$a = 0{\cdot}992 \text{ per centimetre.}$$

As regards the coefficient τ of the reflection on the silvered surface, it varies with the wave length, as is the case with the reflective power of all metals. It is known, however, that for silver this variation is slight, changing from the value of 0·906 for the most refrangible radiations to the

value 0·946 for extreme red, that is to say, an average of from 92·6 to 93 for the most highly illuminating central part of the spectrum.

A mean average value of the coefficient τ can be taken as 0·93, assuming, of course, that the silvering is in perfect condition.

If these three values are introduced into the preceding formula, it is found that, for a parabolical glass mirror having a thickness of 1 centimetre, the total efficiency is

$$\rho = 0{\cdot}915$$

However, as previously stated, formula (17) assumes that all the rays reflected at the entry of the glass remain within the beam of light, a condition which is far from always being realised. Where it is not realised, the value r disappears and the total efficiency falls to 87 per cent.

Efficiency of the Front Glass.—The plain glass pane, which is placed at the front of the searchlight, is also a cause of loss. The value of the efficiency is given (using the same notations as before) by the following formula :—

$$\rho = \frac{(1 - r)^2 a^e}{1 - r^2 (a^e)^2} \tag{18}$$

By introducing into this value the coefficient given above, *i.e.*,

$$r = 0{\cdot}045 \qquad a = 0{\cdot}992$$

the value of the efficiency is found to be $\rho = 0{\cdot}91$ to $0{\cdot}92$, according to the thickness of the glass.

A door of plain glass having a thickness of 5 millimetres has an efficiency of approximately 0·911.

To the actual loss in the glass front must be added the loss caused by the joints and bevels of the glass panes if not in a single piece. This loss approximates 1 per cent.

Shadow Losses due to the Lamp.—The shadow effect due to the lamp is mainly caused by the metal rods which penetrate into the interior of the searchlight barrel, for regulating the movements of the carbons and to adjust their position.

There is a loss of light due to the limbs of the carbon-holders and to the carbon-holders themselves, also to the apparatus for catching the pieces of coalescent carbon for protecting the mirror, and to the flexible cable which connects the carbon-holders to the lamp.

These losses of light are all the more important in actual practice if the searchlight and the lamp are themselves of large dimensions; relatively, however, the shadow losses due to the lamp decreases in proportion to the increased size of the searchlight.

Losses due to the Flashing Shutters.—In modern searchlights, more especially naval searchlights and the greater number of those used by the land forces, the light beam is as a rule masked by a system of louvre or flashing shutters, which, when closed, cover one another in such a manner as to prevent any leakage of light, and when the beam of light is exposed these shutters assume a position parallel to the direction of the light beam. The thickness of the louvres or segments, and of the joints necessary to enable them to effectively cover each other, cause losses which are by no means negligible.

Total Efficiency.—In Table V. is shown the luminous efficiency corresponding to each part of the searchlight

TABLE V.—EFFICIENCY OF SEARCHLIGHTS.

		Diameter.									
		Metres. 0·30	Metres. 0·40	Metres. 0·50	Metres. 0·60	Metres. 0·75	Metres. 0·90	Metres. 1·10	Metres. 1·20	Metres. 1·50	Metres. 2·00
Practical Efficiency.	Reflecting Mirror. . .	0·85	0·85	0·85	0·85	0·85	0·85	0·85	0·85	0·85	0·85
	Lamp	0·849	0·896	0·901	0·916	0·932	0·944	0·940	0·942	0·947	0·955
	Plain Front Glass . .	0·915	0·915	0·915	0·915	0·915	0·915	0·915	0·915	0·915	0·915
	Joints in Panes of Front Glass	0·99	0·99	0·99	0·99	0·99	0·99	0·99	0·99	0·99	0·99
	Flashing Shutters . .	0·792	0·845	0·847	0·853	0·880	0·901	0·896	0·887	0·881	0·907
Total Efficiency without Flashing Shutters		0·654	0·690	0·694	0·705	0·718	0·727	0·724	0·725	0·729	0·735
Total Efficiency with Flashing Shutters		0·518	0·583	0·588	0·602	0·631	0·655	0·648	0·643	0·642	0·677

which causes a loss of light either through absorption or through shadow. This table is applicable to the various sizes of a standard series of searchlights. The last two lines of the table give the total efficiency of the projector, with or without flashing shutters.

CHAPTER IV

PRACTICAL VALUE OF THE ILLUMINATION FROM SEARCHLIGHTS

KNOWING the theoretical value $\epsilon_{1,000}$ of the illumination from a searchlight, at a distance for instance of 1,000 metres, as set out in Tables I. and II., and with a knowledge of the total efficiency of each size of searchlight, it becomes an easy matter to calculate the value of the practical illumination ϵ_p, that is to say of the resultant illumination, taking into account the losses of the individual parts of the searchlight.

In Table IV. are shown the values of the illumination for low and high voltage carbons, for a given size of searchlight, with three different focal lengths, corresponding to those in the preceding Tables I. and II.

It has also been shown that the value of this practical illumination for searchlights with and without flashing shutters is by no means a negligible quantity.

The values given in Table IV. may be used as a basis for the practical determination of the range of a searchlight, a calculation involving the consideration of various conditions and problems which will be dealt with in the second part of this Memorandum.

If the practical values of the illumination given in the preceding table are examined, it will be seen that they increase regularly with the diameter of the searchlight.

In Fig. 5 is shown the values of ϵ_p corresponding to low voltage arcs with a focal length equal to 40 per cent. of the mirror diameter and without flashing shutters. The points

TABLE VI.—AVERAGE PRACTICAL ILLUMINATION AT A DISTANCE OF 1,000 METRES.

ϵ_p

Diameter of Mirror.		Low Voltage.			High Voltage.		
		$\Delta = 3f.$	$\Delta = 2{\cdot}5f.$	$\Delta = 1{\cdot}666f.$	$\Delta = 3f.$	$\Delta = 2{\cdot}5f.$	$\Delta = 1{\cdot}666f.$
Metres.		Lux.	Lux.	Lux.	Lux.	Lux.	Lux.
0·30	Without Flashing Shutters	2·5	3·01	3·67	4·66	5·72	7·15
	With ,, ,,	1·98	2·48	2·91	3·69	4·53	5·66
0·40	Without ,, ,,	3·99	4·80	5·86	7·81	9·54	11·97
	With ,, ,,	3·37	4·06	4·94	6·60	8·07	10·11
0·50	Without ,, ,,	7·27	8·78	10·66	11·30	13·82	17·37
	With ,, ,,	6·16	7·44	9·04	9·57	11·72	14·72
0·60	Without ,, ,,	9·96	12·00	14·63	15·97	19·55	24·60
	With ,, ,,	8·51	10·25	12·50	13·64	16·70	21·00
0·75	Without ,, ,,	14·60	17·56	21·41	23·42	28·58	35·90
	With ,, ,,	12·84	15·44	18·81	20·60	25·10	31·53
0·90	Without ,, ,,	18·70	22·53	27·42	31·50	37·27	46·75
	With ,, ,,	16·84	20·30	24·70	28·38	33·56	42·10
1·10	Without ,, ,,	21·47	31·78	38·65	41·25	50·60	63·70
	With ,, ,,	19·22	28·45	34·60	36·93	45·30	57·05
1·20	Without ,, ,,	29·65	35·73	43·40	47·60	58·00	71·00
	With ,, ,,	26·30	31·70	38·50	42·20	51·40	63·00
1·50	Without ,, ,,	40·86	49·20	60·00	71·70	87·50	110·00
	With ,, ,,	36·00	43·30	52·85	63·10	77·00	96·80
2·00	Without ,, ,,	73·10	88·20	107·50	117·80	143·80	181·50
	With ,, ,,	66·30	80·00	97·60	107·00	130·50	164·80

shown on this diagram are summarised in Table VI. Two different curves have been prepared passing through the greater number of the experimental points, the third being an average showing the minimum deviation from the various calculated values.

The following is the equation of this curve :—

(19) $\epsilon_p = 0{\cdot}00948\ \Delta^{1{\cdot}72}$, where Δ is given in centimetres.

It shows that the illumination ϵ_p of the searchlights increases less rapidly than the square of the diameter.

Table VII. shows the deviations of this from the actual values. The average quadratic error does not exceed 1·13 per cent.

The statement is often made that the illumination

TABLE VII.—PRACTICAL ILLUMINATION FOR A SERIES OF SEARCHLIGHTS WITH A FOCAL LENGTH EQUAL TO 40 PER CENT. OF THE REFLECTOR DIAMETER.

The formula deduced from a logarithmic diagram is: $\epsilon_p = 0{\cdot}00948\ \Delta^{1{\cdot}72}$.

Δ In Centimetres.	ϵ_p Ascertained.	ϵ_p Calculated.	Difference.		Difference per cent.		Square of the Difference.	Remarks.
			+	−	+	−		
30	3·01	3·29	0·28	—	9·35	—	0·078	Average square = $\frac{12{\cdot}977}{10}$
40	4·80	5·40	0·60	—	12·5	—	0·360	
50	8·78	7·93	—	0·85	,,	9·75	0·722	
60	12·00	10·85	—	1·15	,,	9·6	1·32	
75	17·56	15·92	—	1·64	,,	9·35	2·69	Average error = $\sqrt{1{\cdot}2977} = 1{\cdot}135$.
90	22·53	21·79	—	0·74	,,	3·28	0·547	
110	31·78	30·76	—	1·02	,,	3·15	1·040	
120	35·73	35·73	0	—	0	,,	0	
150	49·20	52·44	3·24	—	6·4	,,	10·5	
200	88·20	86·03	—	2·17	,,	2·46	4·72	
					28·25	37·59	12·977	

Average arithmetic error per cent. $\frac{28{\cdot}25 - 37{\cdot}59}{10} = 0{\cdot}934$.

Average quadratic error: $\sqrt{1{\cdot}2977} = 1{\cdot}135$.

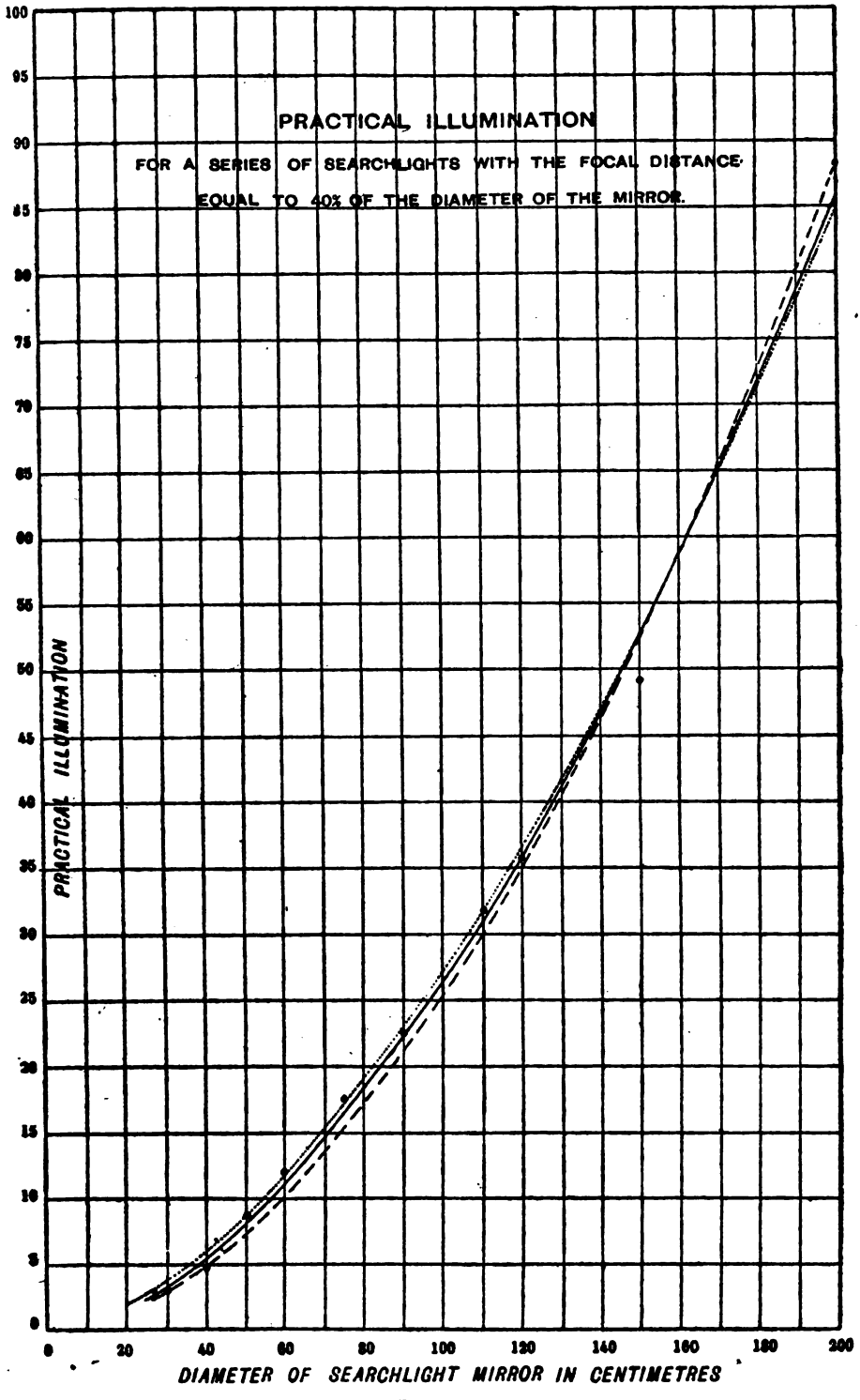

PRACTICAL ILLUMINATION
FOR A SERIES OF SEARCHLIGHTS WITH THE FOCAL DISTANCE
EQUAL TO 40% OF THE DIAMETER OF THE MIRROR.
PRACTICAL ILLUMINATION
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
200
DIAMETER OF SEARCHLIGHT MIRROR IN CENTIMETRES

FIGURE 5

increases with the square of the mirror diameter, but, as previously indicated, the actual increase is not so high, although it approaches this ratio.

Fig. 6 has been drawn under the same conditions, but for a high voltage series of searchlights without flashing shutters and focal length equal to 60 per cent. of the diameter. (See Table VI.)

The following is the equation of the curve which corresponds to the minimum deviations :—

$$\epsilon_p = 0{\cdot}02305\ \Delta^{1{\cdot}72} \tag{20}$$

where Δ is given in centimetres.

It is rather remarkable to realise that the illumination is a function of the same exponential as the diameter of the reflector.

TABLE VIII.—PRACTICAL ILLUMINATION FOR A SERIES OF SEARCHLIGHTS WITH A FOCAL LENGTH EQUAL TO 60 PER CENT. OF THE REFLECTOR DIAMETER.

The formula deduced from a logarithmic diagram is: $\epsilon_p = 0{\cdot}02305\ \Delta^{1{\cdot}72}$.

Δ In Centimetres.	ϵ_p Ascertained.	ϵ_p Calculated.	Difference.		Difference per cent.		Square of the Difference.	Remarks.
			+	−	+	−		
30	7·15	7·07	—	0·08	—	1·16	0·006	
40	11·97	11·59	—	0·38	—	3·17	0·144	
50	17·37	17·02	—	0·35	—	2·01	0·122	
60	24·60	23·28	—	1·32	—	5·36	1·74	
75	35·90	34·17	—	1·73	—	4·82	3·00	
90	46·75	46·75	0	—	0	,,	0	
110	63·70	66·03	2·33	—	3·66	,,	5·42	
120	71·00	76·69	5·69	—	8·00	,,	32·3	
150	110·00	112·50	2·5	—	2·27	,,	6·25	
200	181·50	184·60	3·1	—	1·71	,,	9·6	
					15·64	16·52	58·582	

Average arithmetic error per cent. $\frac{15{\cdot}64 - 16{\cdot}52}{10} = 0{\cdot}088$.

Average quadratic error: $\sqrt{5{\cdot}85} = 2{\cdot}42$.

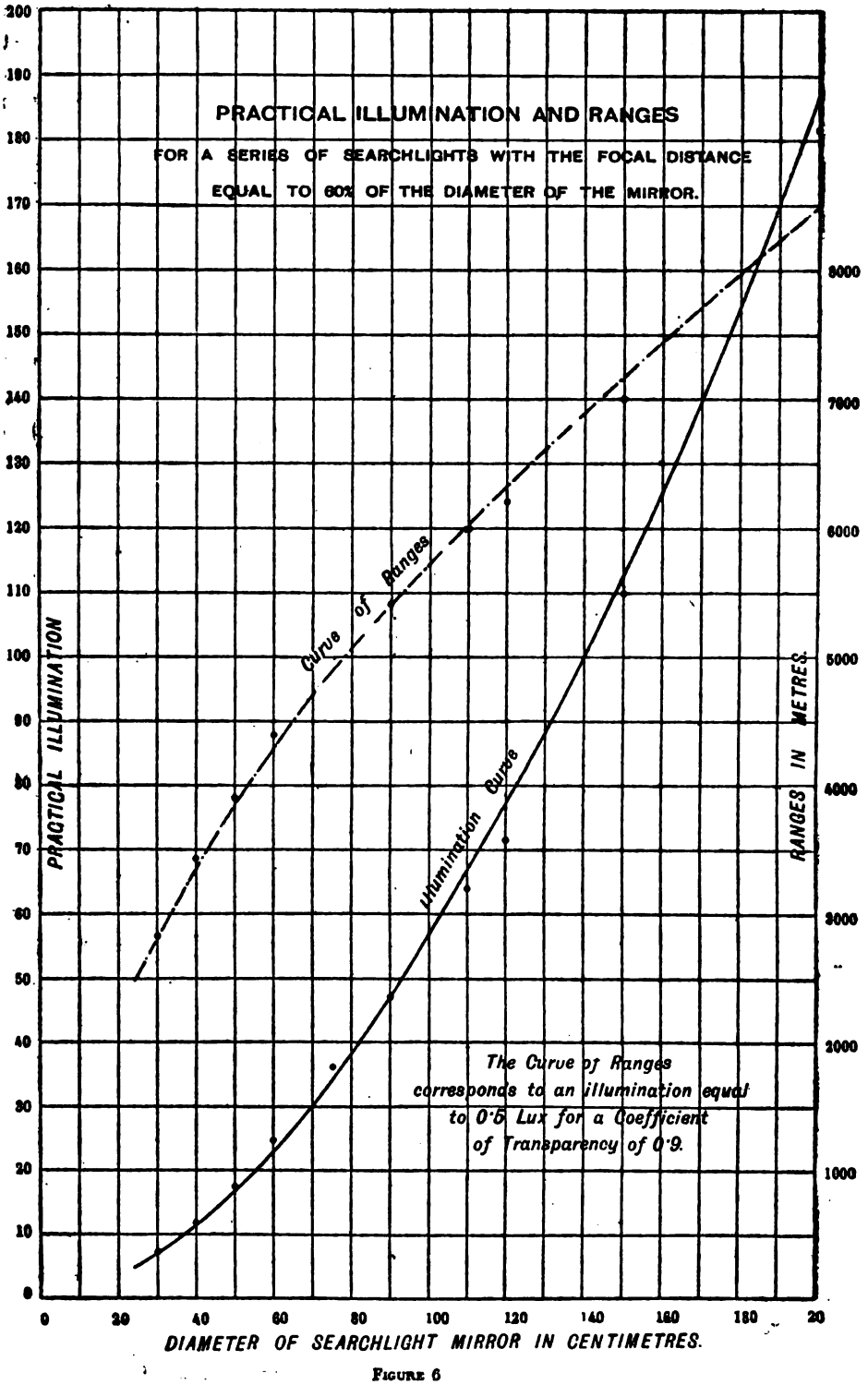

PRACTICAL ILLUMINATION AND RANGES
FOR A SERIES OF SEARCHLIGHTS WITH THE FOCAL DISTANCE
EQUAL TO 60% OF THE DIAMETER OF THE MIRROR.
PRACTICAL ILLUMINATION
RANGES IN METRES.
Curve of Ranges
Illumination Curve
The Curve of Ranges
corresponds to an illumination equal
to 0·6 Lux for a Coefficient
of Transparency of 0·9.
DIAMETER OF SEARCHLIGHT MIRROR IN CENTIMETRES.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
1000
2000
3000
4000
5000
6000
7000
8000
0
20
40
60
80
100
120
140
160
180
200

FIGURE 6

The deviations of this curve from the experimental points have also been shown in Table VIII., the average quadratic error being 2·42 per cent.

In Fig. 6 is shown a curve of the ranges for the same series of searchlights, to which reference will again be made in the second part of this work.

THE INFLUENCE OF THE CURRENT, VOLTAGE AND THE DIAMETER OF THE POSITIVE CARBON ON THE PRACTICAL ILLUMINATION OF SEARCHLIGHTS.—It may be asked what is the influence of the variation in the current of the lamp, and of the possible modifications in the diameter of the carbons, on the value of the illumination.

In the preceding tables are given the diameter of the positive both as regards the use of ordinary voltages and of high voltages. No indication is given of the diameters of negative carbons obtained from actual experience, these varying in a corresponding manner to the diameters of the positive.

A question which it seems reasonable to ask oneself in the case of a searchlight in which the diameter and the focal length of the reflector are given is the following:—What are the most advantageous diameters to be chosen for the carbons and the corresponding values of current and voltage?

We are going to examine as to whether it is possible to solve this question.

VARIATION OF THE ILLUMINATION WITH THE CURRENT AND THE VOLTAGE FOR CARBONS OF GIVEN DIAMETERS.—Remembering that the expression for the theoretical illumination is as follows:—

$$\epsilon_t = 1{\cdot}273\,\varphi\,\frac{If^2}{l^2\delta^2} \qquad (15)$$

it is seen in this expression that if the diameter of the reflector and its focal length remain constant, as well as the diameter of the carbons, the only variables are the values φ and δ^2, or $\frac{\varphi}{\delta^2}$.

On the other hand we have found that the luminous flux φ received by the reflector was given by the expression $\varphi = K\Phi$, in which K, or coefficient of utilisation, remains constant with the focal length, the solid angle of the utilised flux itself being constant.

The value of the total theoretical flux is given by formula (4).

As regards the diameter of the crater, this has been determined by formula (7).

One thus finds

$$\Phi = mW + n \qquad \delta^2 = a^2DI$$

The energy expended within the arc is represented by the expression $W = EI$.

The ratio $\frac{\varphi}{\delta^2}$, which is the only variable in the expression of the illumination, is therefore represented by the quantity

$$(21) \quad \frac{\varphi}{\delta^2} = \frac{K\Phi}{\delta^2} = \frac{K\,(mW + n)}{a^2DI} = \frac{K}{a^2D}\left[mE + \frac{n}{I}\right]$$

In this expression, KD and a^2 do not vary.

Consequently the only variable is

$$(22) \qquad mE + \frac{n}{I}$$

If the practical coefficients are introduced into this expression, one arrives finally at the proportional value

$$(22) \qquad 18{\cdot}06\ E + \frac{9740}{I}$$

The question now is to find out to what extent this quantity varies with the current and the voltage.

The best way is to take an example.

(1) Let us take a pair of carbons of 28 millimetres positive and 13 millimetres negative, which burn with a current varying from 70 to 140 amperes.

Table IX. gives for this particular pair of carbons, the value of the formula (22) stated above, for each value of current and voltage chosen for the tests.

(2) The same calculations were employed for another pair of carbons, 31·5 millimetres positive and 14 millimetres negative.

We assume that the current varies in this pair of carbons from 100 to 160 amperes. The same Table IX. shows the value of the variable ratio for each value of the current. It is sufficient to examine the table in question to realise that, in the two chosen examples, the lighting increased in proportion to the increase of current.

Thus, in the first example, by varying the current from 70 to 140 amperes the increase is equal to 5·7 per cent.; and the minimum illumination at 100 amperes is ascertained. By varying the current from 100 to 140 amperes the increase would be slightly higher, about 6·2 per cent.

It is therefore advantageous to increase the current in the carbons of the specified diameter.

Practical experience has moreover shown that the most satisfactory current for this positive diameter is 120 amperes, both as regards the burning hours and the operation, *i.e.*, the size of the arc flame, and amount of deposit produced by the arc.

In the second example it was ascertained that, by varying from 100 to 160 amperes, the increase in the lighting is equal to 12·6 per cent. It is therefore by no means negligible.

TABLE IX.

Carbon Sizes in Millimetres.	Values of the Expression $18{\cdot}06\ E + \frac{9740}{I}$									
	Volts.	Amperes.	Volts.	Amperes.	Volts.	Amperes.	Volts.	Amperes.	Volts.	Amperes.
Diameter of positive 28 .	48	70	50	100	52	120	54	130	55	140
Diameter of negative 13 .	1006		1001·40		1021·10		1050·9		1062·55	
Diameter of positive 31·8.	49	100	53	130	56	150	58	160	55	140
Diameter of negative 14 .	982·40		1031·9		1075·9		1108·85		1062·55	

The most satisfactory results in practice have been obtained with a current of 150 amperes.

During the last few years practical experience has indicated that it is advantageous to increase the maximum current in carbons of given diameters used up to the present. Thus, some ten years ago it was usual to use positive carbons 30 millimetres diameter with a current of 100 amperes; whereas, as is shown by the second example just analysed, this current is too small for the same carbon diameter, and could be increased with advantage.

It is needless to say that, whatever may be the theoretical reasons which justify such an increase in the current, it has been necessary, in order to realise such progress, to obtain from the manufacturers carbons of a more homogeneous quality as regards the materials of which they are composed, and also of more careful manufacture.

It is not without interest to point out that, in the calculation of these two examples, the luminous efficiency is higher with positive carbons of 28 millimetres than with those of 31·5 millimetres for the same current.

Thus the value of the ratio (22) is 1001·40 for 100 amperes with the first example and 982·40 with the same current for the second example, that is to say, an increase of 2 per cent.

When increased to 130 amperes with carbons of 28 millimetres the result is 1050·9 and with carbons of 31·5 millimetres 1031·9, which is an increase of nearly 2 per cent. for carbons of 28 millimetres.

This comparison justifies what has been stated above—*i.e.*, that, in a general way, the luminous efficiency of large carbons is inferior to that of carbons of a smaller diameter.

VARIATION OF THE ILLUMINATION WITH THE CURRENT, VOLTAGE AND DIAMETER OF THE CARBONS.—This question is quite a general one, and can only be answered, in view of the large number of variables, by choosing a specified series of carbons, together with current values and voltages, which practical experience has shown to be most suitable for the specified carbon dimensions.

The value of the ratio which indicates the variation of the illumination, namely $\frac{\varphi}{\delta^2}$, is given by the expression $\frac{mW + n}{DI}$, in which the diameter of the positive also varies.

In Table X. are shown the variations of the expression

$$(23)\quad \frac{mW + n}{DI} = \frac{I}{D}\left[mE + \frac{n}{I}\right] = \frac{I}{D}\left[18{\cdot}06\,E + \frac{9740}{I}\right]$$

This table is divided into two parts, the first series referring to low voltage carbons, and the second series to high voltage carbons. An examination of the decrease of the ratio which expresses the value of the illumination will show that it is considerable, both as regards low voltage and high voltage carbons.

TABLE X.

—	Low Voltage Carbons.							
Diameter of the positive (mm.) .	22	23	25	28	30	32	38	
Intensity (amperes).	50	60	70	90	100	110	150	
Voltage (volts)	47	48	49	50	51	52	56	
Value of the expression (23) . .	47·4	44·7	41·0	36·1	34·0	32·1	28·3	
—	High Voltage Carbons.							
Diameter of the positive (mm.) .	19	20	22	25	28	30	32	35
Intensity (amperes)	60	70	80	110	130	150	175	200
Voltage (volts)	62	65	66	69	72	75	77	78
Value of the expression (23) . .	67·8	64·1	59·9	49·7	49·4	47·6	45·4	41·8

This means that if in a searchlight where the reflector has a specified diameter and focal length the values of the current shown in Tables Nos. I. and II. were to be successively tried, varying the diameter of the carbons in such a manner as to maintain the current density constant, the value of the illumination would decrease in the same proportion as the ratio (23). This decrease would not be less than 40 per cent. when passing from 50 to 150 amperes for low voltage carbons and 38 per cent. when passing from 60 to 200 amperes for high voltage carbons.

These facts having been ascertained, the question may be raised why, in the case of searchlights burning a small current, one is not satisfied to simply use corresponding carbons of small diameter, seeing that in practice the illumination is stronger with the higher current intensities. The reason is that when carbons of small diameter and low current values are used, the dimension of the luminous crater is also very small. The diameter of the crater has in fact been given by formula (7), which shows that it varies as the square root of the product of the diameter of the positive by the intensity of the current. The illuminated field therefore becomes considerably reduced.

With low voltage carbons for the same focal length, that is to say, within the same reflector, it will immediately be seen that, in virtue of formula (7), the diameter of the lighted zone at 50 amperes only represents 44 per cent. of its dimension at 150 amperes.

With high voltage carbons this relation becomes only approximately 40 per cent.

In order, however, to see objects clearly and to discover them at night, it is essential that the illuminated field shall attain sufficiently large practical dimensions. When an object illuminated by a searchlight has to be recognised it is necessary that more should be illuminated than one section, which might be insufficient to thoroughly define it.

Let us suppose, for instance, that an attempt is made to recognise a village. If, for example, it is only possible to show up one house, or perhaps just a few, it will be quite possible to make a mistake or to hesitate in coming to a conclusion; should, however, the field be sufficiently large to embrace the greater part of the village an error will not be possible.

It is therefore a visual necessity to obtain a field of sufficient dimensions, and it is this necessity which compels the use of higher current values as the diameter itself of the reflector and the focal length increases. If one were to be simply satisfied with the luminous efficiency of the arc itself, there would be no occasion to exceed certain current values which can be determined by calculation.

Intrinsic Radiation.—The expressions previously considered, and also the variations studied, represent in reality the value of the "intrinsic radiation," that is to say, the luminous flux emitted by a unit surface of the crater.

It may be written that the intrinsic radiation of the crater is nothing else but

$$\frac{\Phi}{S} = \frac{mW + n}{bDI} = \frac{I}{b}\left[\frac{mE}{D} + \frac{n}{DI}\right] \tag{24}$$

With a given size of reflector the value of the practical illumination is directly proportional to the intrinsic radiation.

CHAPTER V

MANGIN SEARCHLIGHTS

In concluding the general study of the illumination from searchlights, it may be of advantage to refer to the special results obtained with Mangin searchlights, which were the only ones employed for many years.

It is well known that the invention of Colonel Mangin, of the French Military Engineers, was put into practical use for the first time in 1877, and consisted of a glass reflector, having a double spherical surface, formed of a concavo-convex lens silvered on its convex face.

In this optical combination the ray of curvature of the concave refracting surface is smaller than the ray of curvature of the convex reflecting surface. The reflector therefore has its minimum of thickness in the centre and its maximum at the edges.

From an optical point of view, this apparatus amounts to a juxtaposition of a concavo-convex lens acting by refraction, with a concave mirror acting by reflection. Properly calculated, such a reflector causes practically no divergence of the light rays having the same wave length. The spherical aberration of the Mangin mirror is almost *nil* so long as the focal distance of the whole does not fall below 70 per cent. of the diameter. By improvements in its manufacture, the firm of Sautter-Harlé has succeeded in producing reflectors having diameters up to 1·50 metres.

It was some twenty years after his invention, about the year 1896, that, owing to the influence of the Germans, who contended that parabolic glass reflectors with a short focal

length such as they were then constructing were far superior to the other designs, the expert officers requested the makers to supply a Mangin reflector having a shorter focal distance in order to obtain a more extensive illuminated field. After numerous efforts, the firm of Sautter-Harlé succeeded in cutting, on this principle, reflectors the focal length of which was only equal to one half the diameter.

However, with such short focal lengths, the thickness of the glass at the edges of the reflector becomes considerable, and the losses by absorption and by internal dispersion are notably high. The chromatic dispersion at the edges is also greater. Finally, the greater the increase in the thickness of the glass the heavier does the mirror become, and the chances of fracture, owing to the slow crystallisation of the glass, are more numerous.

The considerations which have been referred to in the preceding chapters in respect of the illumination from the mirrors prove that nothing can be gained by shortening the focal length too much. From the point of view of the illumination, and also of the efficiency, the series of Mangin mirrors, designed with a focal length equal to 0·7 of the diameter, are certainly the best.

Concentration of the Beam of Light in a Mangin Searchlight.—The superiority of the Mangin mirror from an optical point of view over the parabolic glass reflector, and also over all other reflective devices, results from the following:—

With the same size of mirror, and for the same utilised flux within the solid angle, the point of which is placed at the focus, the focal length of the mirror is always greater than that of the parabolic mirror.

The result is that the zone illuminated by the Mangin mirror, given an equal luminous flux, always has a smaller

TABLE XI.—MANGIN SEARCHLIGHTS OF LONG FOCAL LENGTH AND INCLINED LAMP.

Diameter of the Mirror in Metres. Δ	Amperes. I	Arc Voltage. E	Diameter of the Positive Carbon in Millimetres. D	Diameter of the Crater in Millimetres. δ	Theoretical Flux in Lumens. Φ	Average Theoretical Illumination at 1,000 Metres in Lux.	Efficiency of the Searchlight without Flashing Shutters. ρ	Average Practical Illumination at the Distance of 1,000 Metres in Lux.	Focal Length in Millimetres. f	Coefficient of Utilisation. K
0·60	65	45	24	13·60	62,590	27·42	0·705	19·33	420	0·360
0·75	80	47	27·5	16·13	77,740	37·75	0·718	27·10	525	0·360
0·90	110	48	30	19·75	105,170	48·92	0·726	35·51	629	0·360
1·50	200	62–65	43	31·9	231,940	118·20	0·712	84·20	1,062	0·361

Width of the illuminated zone at 1,000 metres.

Diameter of the Mirror.	
Metres.	Metres.
0·60	32·40
0·75	30·75
0·90	31·40
1·50	30·05

diameter than is the case with the parabolic mirror, but the illumination per unit of surface of the zone is greater in the ratio of the square of the two focal lengths.

For example, the series of Mangin reflectors having a focal length of 0·7 of the diameter corresponds to an angle of utilised flux of 82°36′; whereas a parabolic mirror enclosing the same angle of flux has a focal length of only 0·663 of the diameter.

If one therefore compares a Mangin reflector to a parabolic reflector illuminated from the same source of light and utilising the same luminous flux, the parabolic reflector will illuminate a zone having a diameter 5·6 per cent. greater than that of the zone illuminated by the Mangin mirror; but the illumination from the parabolic mirror will only be 89·6 per cent. of the Mangin mirror.

This advantage is integrally maintained so long as the Mangin mirrors have a diameter which does not exceed 0·90 metre. If this diameter is exceeded, the large Mangin mirrors have an efficiency which is slightly below that of the parabolic mirrors, owing to the increased thickness of the glass at the edges. However, this loss, which does not exceed 2 to 3 per cent., does not sensibly reduce the superiority of illumination of the Mangin mirror, with a long focal length, over the parabolic mirror.

Practical Illumination of Mangin Searchlights.—In Table XI. are given all the values which make it possible to determine the average practical illumination of a Mangin searchlight of long focus, and for four different diameters, *i.e.*, 0·60, 0·75, 0·90 and 1·50 metres. In the same table is also shown the width of the illuminated zone at 1,000 metres distance.

It is therefore seen that, in a general way, if the results of this table are compared with those of Table VI., for a focal

length equal to 60 per cent. of the diameter, the practical illumination of a Mangin searchlight without flashing shutters is on an average 30 per cent. higher than that with a parabolic mirror of similar dimensions and tests.

Unfortunately for the invention of Colonel Mangin, the fact that his reflector has to be constructed of glass has caused it to be gradually abandoned, as is also the case with glass parabolic mirrors. It has become more and more recognised that it is essential for the reflector of a searchlight, *i.e.*, its most delicate part, to be so constructed as not to break when hit by a bullet, and not be affected by shocks during transport or caused by gunfire, nor by sudden and extreme changes of temperature, to which glass mirrors are sensitive.

Gilded concave metallic mirrors are becoming more generally used owing to their solidity of construction, but can only be given one single curve, *i.e.*, the parabolic curve, therefore the advantage of concentrating the beam of light as provided by the Mangin mirror can no longer be utilised in this system. Its military qualities, however, cause it to be preferred to all other types of glass reflectors.

Nevertheless, it is desirable to recall the remarkable French invention of Colonel Mangin, which dates back nearly forty years, and has not up to the present been surpassed by any other combination from the point of view of optical reflective power.

PART II

Range of Electric Searchlights

General Remarks on the Range of Electric Searchlights

The various elements which determine the range of electric searchlights may be divided into two classes—

(1) The internal elements, which depend on the searchlight itself and which regulate the luminous flux;
(2) The external elements, which act on the utilisation of the luminous flux, once it has been projected to a distance by the searchlight.

The internal elements are essentially—

The power of the electric arc, which constitutes the source of light;

The diameter of the reflector and its focal length;

The efficiency of the reflector and that of the searchlight which contains it.

The external elements are—

The transparency of the atmosphere;

The distance at which the objective is placed;

The dimensions and the nature of the objective, its colour and the colour of the background;

Finally, the distance at which the observer, who is examining the object, is from the searchlight and objective.

The influence of the internal elements has been studied in the first part of this book.

On analysing the influence exerted by the exterior elements the effect of the atmospheric transparency is primordial. According as to whether the atmosphere is clear or misty, the luminous flux traverses with slight or heavy losses, the distance which separates the searchlight from the objective, as also the distance which separates the objective from the eye of the observer. When the atmosphere is charged with humidity or dust, the losses may become such that the flux which reaches the eye of the observer is insufficient to affect the retina and to cause the sensation necessary for the visibility of the objects.

It must be observed that the effect of the transparency of the atmosphere acts on the double range, *i.e.*, between the searchlight, the objective and the observer.

The nature of the objective and of its background, as also its dimensions, have an important influence on the visibility. Not only does the visibility depend upon the colour of the objective, but also on its reflecting or diffusing power. Certain objects possess parts having a brilliancy which reflects the light in the direction of the eye of the observer. As a general rule, the objects are simply diffusing. Coloured objects (white or light) often have a high diffusive power approaching the unity. Dark-coloured objects are very absorbent and only reflect a small percentage of light in the direction of the observer. The colour of the background gives rise to an effect of contrast which may, in certain cases, greatly favour the visibility. Thus a light object on a dark background, or a dark object on a light background, will naturally be more easily distinguishable than if the tints of the two are more or less similar.

Finally, the dimensions of the object act on the phenomenon of visual acuity or sharpness ; the human eye is unable to perceive objects, even if extremely luminous, which are below certain angular dimensions, the average

value of which has been fixed by practice. If an object having dimensions corresponding to a given visual sharpness is placed further away from the observer, it will require considerably more illumination than would result simply from a prolongation of the distance, or from an increase of the atmospheric absorption.

M. Blondel has recently indicated very forcibly the general formulæ which control the range of searchlights, taking into account the visual acuity, these will be referred to later.

CHAPTER VI

GENERAL LAW GIVING THE VALUE OF THE RANGE OF AN ELECTRIC SEARCHLIGHT, APART FROM THE VISUAL SHARPNESS

DEFINITION OF THE FORMULA OF RANGES.—The formula for the range of searchlights, apart from the visual sharpness, was given for the first time by M. Blondel in 1899 in an unpublished Work, which he has been kind enough to communicate to us.

This formula reads as follows :—

$$\epsilon_0 = \epsilon_1 \frac{a^{l+l'}}{l^2} \frac{I}{10^6} \times j \tag{25}$$

When examining the various elements which enter into this formula it will be shown how it can be proved with absolute exactness.

Fig. 7 gives in c the path followed by the luminous flux in the most general case.

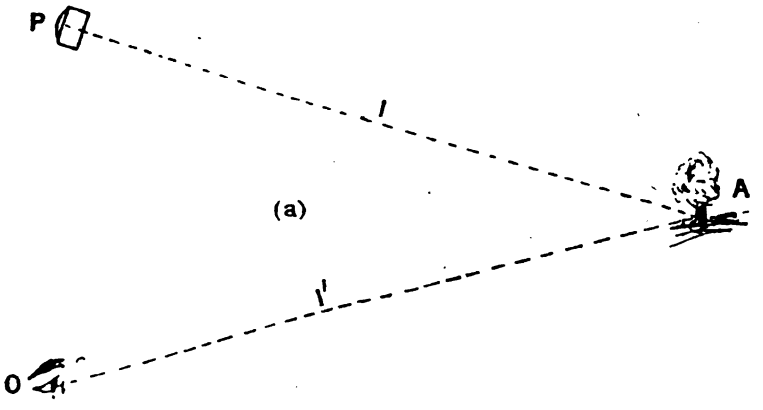
P is the searchlight illuminating an objective A.

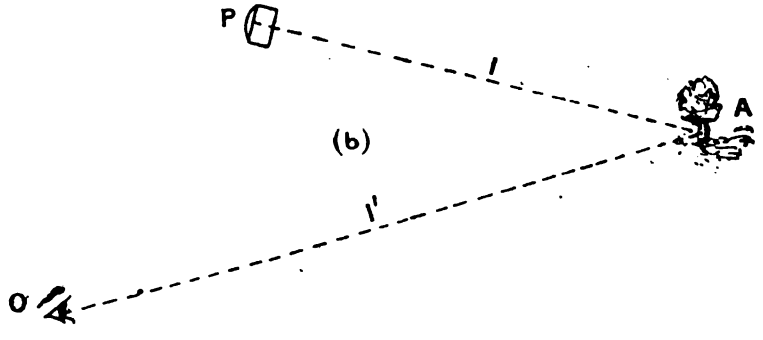
The distance which separates P from A is shown by l.

The luminous flux, after having struck the object A, returns to the eye of the observer placed at O, along a rectilineal path the length of which is l'.

As a general rule, the lengths l and l' may be of any dimension, equal or different, l being longer or shorter than l'.

In the formula, ϵ_0 is assumed to show the residual illumination which reaches the eye of the observer, that is to say, the illumination produced by the luminous flux which has traversed the total range $l + l'$.





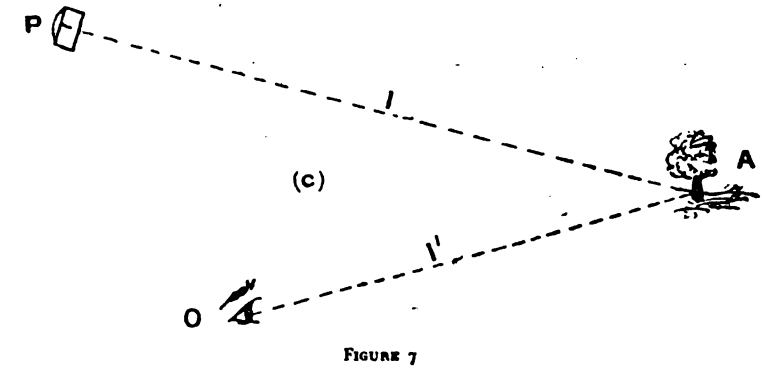


FIGURE 7

Assume ϵ_I to show the illumination by the searchlight of an object normally placed at its axis and at unit distance.

In order to calculate the lighting of a luminous source, the metre is taken as a unit of distance.

The value ϵ_I is therefore the illumination at a distance of 1 metre from the searchlight. As a metre is an inconvenient unit in the case of searchlights, the ranges of which are calculated in kilometres or fractions of kilometres, it is preferable to calculate the illumination by a searchlight at a distance of 1 kilometre.

That is why the formula contains in the denominator the figure 10^6. The illumination from a searchlight, given in the second member of the formula, may therefore be represented by the value $\frac{\epsilon_I}{10^6}$, which is equal to the practical illumination at a distance of 1 kilometre.

In Part I. of this book the illumination was represented by the symbol ϵ_p.

One has therefore

$$\frac{\epsilon_I}{10^6} = \epsilon_p$$

The formula may be more easily written :

$$\epsilon_0 = \epsilon_p \frac{a^{l+l'}}{l^2} j \tag{26}$$

The coefficient of atmospheric transparency is represented in the formula by the symbol a. This coefficient expresses the proportion of luminous flux which remains after passing through a layer of air 1 kilometre in thickness. In this definition it is supposed that, at its origin, the luminous flux is the unit, and that after having traversed a distance of 1 kilometre in the atmosphere, it is reduced to the value a, less than unity.

The proportion absorbed is given in this definition by $1 - a$.

The coefficient j, which is also contained in the formula, expresses the proportion of light reflected or diffused by the object illuminated. Comprised also within this coefficient is the effect due to the contrast between the illuminated object and its dark or light background.

It will now be shown how the formula is justified.

First consider the path between the searchlight P and the objective A, the length of which is l, and suppose that the atmospheric transparency is absolute, that is, the air does not absorb any proportion of the luminous flux which traverses it; what will be the degree of illumination of the object?

This illumination will be inversely proportional to the square of the distance l. The value of the illumination at the point A will therefore be

$$\epsilon_\rho \times \frac{I}{l^2}$$

It is well known, in fact, that the luminous flux which emanates from a searchlight has the shape of a cone with a circular base. The working area of the various straight sections of the cone, perpendicular to the axis, therefore goes on increasing as the square of the distance to the summit of the cone, and, as these sections are all traversed by the same luminous flux, the result is that the illumination of each section, that is, the flux per unit of surface, decreases with the square of the distance.

Assume now that the atmosphere possesses its natural power of absorption. Each kilometre of the length l will only allow the proportion a of the luminous flux to pass.

According to a well-known rule, the total proportion of light transmitted from the searchlight P to the object A will be represented by the coefficient a^l.

Consequently, the degree of illumination of the object, taking into account the atmospheric absorption, will be represented by the formula

$$\epsilon_p \frac{I}{l^2} \times a^l$$

Of the luminous flux which reaches the point A, part only will be reflected or diffused in the direction O, that is, towards the eye of the observer. The coefficient j represents this portion. The amount of illumination which will be able to reach the eye of the observer will therefore no longer be that received by the object, but will be represented by the value

$$\epsilon_p \frac{I}{l^2} a^l j$$

This illumination will itself be reduced by the atmospheric absorption exerted on the path AO. The proportion of light transmitted to the point O will only be $a^{l'}$ of the preceding quantity. The amount of illumination ϵ_0 on the eye of the observer, taking into account the atmospheric absorption, will therefore be represented by the value

$$\epsilon_p \frac{I}{l^2} a^l j \times a^{l'} = \epsilon_p \frac{a^{l+l'}}{l^2} j = \epsilon_0$$

which is the general formula (26).

It may be asked why the distance l' does not intervene in the path from the objective A to the eye of the observer O, other than in the exponent of the coefficient of transparency. Again, why does the distance l' not act according to the

inverse ratio of its square, causing the degree of illumination to decrease in the proportion $\frac{I}{l'^2}$, as is the case for the path from the searchlight to the objective.

In order to explain what seems an anomaly, it is necessary to refer back to the theory of vision. The eye is nothing but a sensitive screen, a screen on which is formed an image created by the lens of the crystalline. As the object A observed by the eye gradually recedes, the angle subtended by this object (the summit of which is at the centre of the crystalline) itself gradually diminishes. The dimensions of the image formed on the retina decrease in the same proportion.

The luminous flux per unit of surface, which emanates from the object illuminated and falls on the retina, decreases as the square of the distance, or as the square of the angle subtended by the object. However, as the surface of the retinal image also diminishes as the square of the same angle, the illumination per unit of surface of the retinal image therefore remains constant.

It may therefore be said with certainty that the amount of illumination received by the eye does not decrease in proportion as the distance of the object A from the eye increases. However, the constancy of this retinal illumination has a limit, which is reached when the distance of the object becomes such that the subtended angle only corresponds on the retina to a surface less than a certain limited value. It is known in fact that the sensibility of the eye is only maintained when the retinal image is not less than a given dimension, which corresponds approximately for a piercing sight, to an angle of a minute. This is what is expressed when it is said that the apparent dimensions of the objects must not fall below a maximum value for the visual sharpness. When this limit is reached, the eye no

longer perceives the dimensions of the object, as it sees nothing more than a luminous point. Starting from this distance, the retinal illumination and the impression resulting therefrom again begin to vary as the square of the distance.

In the case of illumination obtained by an electric searchlight, the only useful section in the visual space is that in which the object is always perceived with its lineal dimensions sharply defined, *i.e.*, that it is never reduced to a luminous point. As searchlights are used for the purpose of recognising objects by their shape and dimensions, there can be no question of an exact visibility such as that given by the observation of the stars, or, for instance, of luminous signals from lighthouses to navigators.

It will therefore be seen that the general formula for the range, only admits in the denominator the square of the distance which separates the searchlight from the objective ; whereas the double distance only acts on the coefficient of the transparency.

The formula (26) gives the range in the most general case, but this can, however, be simplified in practice.

While searchlights are working, the observer frequently finds himself placed at a short distance from the searchlight, with the result that the distance between the searchlight and the objective is practically the same as that from the observer to the objective.

Geometrically, this case, which is the most frequent, is rendered by the expression $l' = l$.

The formula then becomes simplified as follows :

$$\epsilon_0 = \epsilon_p \frac{a^{2l}}{l^2} j \tag{27}$$

A study will now be made of the influence of the various elements which compose the general formula for ranges,

and it will be shown how it is possible to vary the values of these various elements.

Coefficient of Reflection and Diffusion of the Illuminated Object.—In the general formula we have included in the coefficient j, the influence of the power of reflection, and also of the power of diffusion of the illuminated object. This same coefficient also includes the influence of the colour of the objects and the contrast between the object and the surrounding background.

It is easy to understand how largely these various elements may vary with the different illuminated objects. The reflective power of a looking-glass, an illuminated window pane, or a brilliant metallic object may vary to a very considerable extent. The same applies to the power of diffusion which varies within wide limits to almost unity according to the nature of the object. The colour of the objects is also of considerable importance. Whereas a dark-coloured object, grey or blue, will only diffuse 10, 15, or 20 per cent. of the light it receives, a red or yellow object will give a proportion three or four times greater. The effect of the contrast between the colour of the object and that of the background (an effect which also depends on the dimensions of the object and of the illuminated background) may vary within very extensive limits.

These considerations show that the value of the coefficient j could only be determined by a very large number of practical tests, seeing that this value changes for each particular case.

In order to calculate the degree of illumination received by the eye of the observer, that is, the quantity of light reflected or diffused by the illuminated object, it would be necessary to be acquainted with all the variables which enter into the determination of the coefficient j.

Such a study has not previously been attempted, and it would require numerous tests in order to obtain results of any practical use.

Endeavour has been made to overcome the difficulty by introducing the notion of the equivalent illumination, which will be defined later.

In an arbitrary manner we give to the coefficient j, for all illuminated objects, the same value which we suppose equal to unity. We thus eliminate the very considerable difficulties of the exact measurement of this coefficient, which, as stated above, comprises not only the physical values of the coefficients of reflection and diffusion, but also the physiological effect of contrast, the experimental determination of which would be a far more delicate operation.

Equivalent Illumination.—The notion of the equivalent illumination is nothing but a definition to facilitate the practical application of the general formula for ranges.

If we suppose that all illuminated objects have the same coefficient j, equal to unity, and if we apply this hypothesis to the various cases which occur in practice, it will be recognised that the illumination calculated in accordance with the formula for ranges (assuming that the distances l and l', the coefficient of transparency a, and the practical illumination of the searchlight ϵ_p are known) leads to a value ϵ_o of the illumination reflected to the eye of the observer.

This value ϵ_o will not be the same for the various objects illuminated. By applying the formula it will be seen that for a light-coloured object of large dimensions the value ϵ_o is lower than for dark-coloured objects of small dimensions. To each illuminated object there will correspond, for the conditions under which the observation has been carried

out, a special value for ϵ_o, this value being determined for the practical limit of visibility at which the object is observed, or, on the contrary, for a range corresponding to a good visibility of the details of the object in question.

It will therefore be possible to determine a table of values calculated by the formula for ranges, for a series of every-day objects, such as those which it is usually desired to illuminate on land and on sea. Each of these values will correspond to a different illumination on the eye of the observer, for the limit of the range of the objects under consideration and whose coefficient j is reduced to unity.

This method of reasoning is not exact from a physical point of view, because it would lead to the statement that the limit of visibility of the human eye for different illuminated objects, corresponds to quantities of light falling on the retina, which are different one from the other. It is quite evident that this is not so. For any given eye the limit of sensibility is more or less the same, whatever may be the objects observed. However, the hypothesis thus set forth, which assumes that all the objects possess the same reflecting and diffusing powers equal to unity, makes it possible to analyse the results of practical tests and to give to each object an equivalent illumination. This will for other cases than those under consideration, permit the calculation of the range of the same object illuminated by different apparatus and under different atmospheric conditions, provided, however, that the new conditions in respect of range do not vary too much from those existing during the typical test.

An example of the application of this method will suffice to explain it.

Supposing that during tests carried out in the Mediterranean, at the port of Toulon for instance, it had been ascertained that a parabolic metallic mirror 1·50 metres

diameter, with a focal length of 0·88 metre and a practical illumination ϵ_p, which, under the actual conditions of working, was equal to 66·5 lux, was able to illuminate a dark-coloured torpedo-boat at a maximum distance of 5,000 metres in winter, under adverse atmospheric conditions corresponding to a coefficient of transparency equal to 0·875 determined by other tests. Supposing also that the same evening another searchlight had been tested, having a metallic mirror 1·50 metre diameter but a focal length of 0·60 metre, corresponding to a practical illumination of 48·5 lux, the second projector giving a maximum range, for the same torpedo-boat, of 4,600 metres.

With the help of these two observations it becomes possible to calculate, in accordance with the general formula for ranges, the value of the equivalent illumination ϵ_0 supplied by the two projectors. Thus for the first searchlight:

$$\epsilon_0 = \epsilon_p \frac{a^{2l}}{l^2} = 66{\cdot}5 \frac{(0{\cdot}875)^{2 \times 5 \text{ km.}}}{5^2} = 66{\cdot}5 \times 0{\cdot}0106 = 0{\cdot}705^{\text{lux}}$$

and for the second searchlight:

$$\epsilon_0 = \epsilon_p \frac{a^{2l}}{l^2} = 48{\cdot}5 \frac{(0{\cdot}875)^{2 \times 4{\cdot}6 \text{ km.}}}{(4{\cdot}6)^2} = 48{\cdot}5 \times 0{\cdot}0145 = 0{\cdot}704^{\text{lux}}$$

It will therefore be concluded from this test that the equivalent illumination of a torpedo-boat similar to that on which the experiment was carried out will be approximately 0·7 lux.

The same method, applied to a large armoured warship, has given, during tests carried out either in the Mediterranean or the Channel, under different atmospheric conditions which it was possible to determine, the value

$$\epsilon_0 = 0{\cdot}23$$

The equivalent illuminations shown in Table XVI., which is referred to later, for a whole series of land and sea objects are therefore fictitious values, and assume that the sensibility of the eye changes with the objects it observes, all these objects invariably sending back to the eye the whole of the luminous flux they receive.

Once the table of the equivalent illuminations has been determined, it becomes possible to calculate for the same objects the ranges under other conditions met with in practice, the general formula being then applied as a first approximation.

Graphic diagrams have been prepared in order to facilitate the practical application of formula (26).

COEFFICIENT OF TRANSPARENCY.—We now come to one of the first problems in the calculation of the ranges of searchlights, *i.e.*, the coefficient of atmospheric transparency:

The methodical determination of the coefficient of transparency has been carried out for all the coasts of France by the French Administration for Lighthouses. The luminous power of the apparatus in lighthouses being known, the observations carried out in respect of the visibility of lighthouses makes it possible to determine the coefficient of transparency with an approximation sufficient for the needs of navigators, and also sufficient for the illumination at a distance by electric searchlights.

In the Memorandum on the power and the range of lighthouses by M. Allard, Engineer-in-Chief for Roads and Bridges, which appeared in 1876 and was published by order of the Minister for Public Works, will be found the method followed in that study and the results obtained thereby.

The determination of the atmospheric transparency is

based on the degree of the average sensibility of the human eye at the maximum range. In this respect M. Allard gives a value of this sensibility which, according to him, would correspond to a tenth of a decimal candle, that is to say, the human eye observes the disappearance of a light of that intensity at an average distance of 1 kilometre, the atmosphere being supposed to be transparent.

More recent experiments than those of M. Allard, together with other considerations, are referred to in our work on a new system of lighthouses,[1] and have shown that the limit as indicated by M. Allard is too small, as far as the visibility of lighthouses is concerned. In the case of electric searchlights, however, the question does not come into consideration, seeing that if M. Allard's coefficients of transparency were affected by a general systematic error this error would have no influence on the calculation of the range of objects illuminated by the searchlights, according to the method we follow.

In practice, the determination of the equivalent illuminations is obtained by the aid of a coefficient of transparency, which is assumed to be exact. By making use of the coefficients of transparency tabulated by M. Allard, and by carrying out the inverse operation for the same object but under different circumstances, the error committed in the first instance becomes automatically corrected.

The method for the application of the general formula for ranges, is therefore independent of all systematic error in the determination of the coefficient of transparency, as is also the case in the determination of the practical illumination of a searchlight. The value of the ranges obtained by calculation apart from the visual sharpness, (once the

[1] "Nouveau Système de Phares à Reflecteurs Métalliques" ("New System of Lighthouses with Metallic Reflectors"), Paris, 1913.

equivalent illumination is known) is therefore found to be independent of such systematic errors.

The coefficients of transparency determined by the Administration for Lighthouses have only been measured along the French coasts. It is certain, however, that at sea the atmospheric transparency becomes reduced owing to the greater humidity of the lower strata of the atmosphere, because the watery globules contained in the atmosphere, even when they appear to be entirely transparent, always absorb a certain proportion of the light.

On the other hand, the air over the earth is generally drier and contains particles of dust, which no longer exist at some distance from the shore. Now, particles of dust constitute an element which is extremely absorbent for luminous flux. As a matter of fact, the results of experiments which have been repeatedly carried out in Paris show that in summer, during a beautiful warm and dry evening, the dust contained in the Parisian atmosphere reduces the coefficient of transparency as much as 0·62 per kilometre, that is to say, each kilometre traversed absorbs 38 per cent. of the luminous flux which it receives.

As no methodical study of the coefficient of transparency over the land has been made, either in France or abroad, it is only possible to reason in a general manner. As a first approximation it is supposed that the coefficients of transparency measured along the coasts are practically maintained over the land for the same latitudes, at least for level countries or those of an average altitude. In the following tables, a certain number of European climates are mentioned which correspond to average coefficients of transparency, the values of which have been measured along the French coast, from the Straits of Dover to the Mediterranean. It is obvious that these values will be subject to revision when methodical tests of transparency have been

carried out in France and abroad. From this hypothesis it is possible to ascertain, to a certain extent, the variation of the coefficient of transparency for land climates. In the calculations and the diagrams which are given later exact results must not be expected in view of the present state of our knowledge of this subject.

In mountainous districts, as soon as a certain altitude is reached, the atmospheric transparency becomes considerable, owing to the dryness and the purity of the air, also that particles of dust entirely disappear above 1,000 metres. This transparency is therefore increased in winter when it snows. Moreover, the effect of the contrast of objects which stand out from a snowy background increases the visibility to a considerable extent.

Further on are given some approximate values of the coefficient of transparency which are applicable to observations in mountainous districts.

In southern climates, such as the coast of the Mediterranean in France, Italy and Spain, and in the whole Mediterranean basin, the average transparency is far higher than over the Atlantic or the Channel.

Finally, in sandy and desert countries, in Africa for instance, and on the shores of the Red Sea, where the English and the Italians have at various times employed electric searchlights, it has been ascertained that the transparency is extremely high and that it almost attains unity.

The coefficient of transparency is usually given per kilometre, which is the unit chosen.

As a general rule three average coefficients are distinguished, the first referring to weather said to be " clear," the second to weather said to be " average," and the third to weather said to be " misty." It must not be imagined that this expression " misty weather " implies actual fog. When there is a real fog, calculations must no longer

be made per kilometre, but per decametre, and even per metre. In the case of thick fogs, an intensity of 10 candle-power, which normally traverses a distance of 7 kilometres under average transparency, only penetrates to a distance of approximately 25 to 30 metres.

It is therefore seen that the words "misty weather" do not in reality imply a real fog; they merely refer to weather which is less transparent than the normal.

Naval and military officers who are in the habit of using searchlights, are well aware of the rapid variations liable to be met with in the atmospheric transparency and of the effects which these variations have on the range of an apparatus within comparatively short periods and during the same evening. The tables which are given, therefore indicate the average and approximate values which it is necessary to be able to employ in actual practice.

An important remark which must never be lost sight of in this question of atmospheric transparency when applied to the range of searchlights, is that the coefficient of transparency always corresponds to a certain probability in respect to the state of the atmosphere. Thus, when a coefficient of average transparency of 0·9 for the whole of the French territory is given for 50 per cent. of the year, it means that if one takes the whole year there will always be a probability of 50 per cent., *i.e.*, one day out of two, in which to obtain a coefficient of transparency of 0·9. If, on the contrary, it is stated that for a given region the coefficient of transparency is 0·95 for two-tenths of the time, it means that one will always be certain to have for two days out of ten an atmosphere of sufficient transparency to allow the passage of at least 95 per cent. of the light per kilometre traversed.

In the tables which follow there is given in respect of each of the coefficients of transparency, the total of the

probability. This total is also given on the practical curves referred to later on; these values are given in various degrees of probability, but in no way are they absolute values, as it was impossible to fix these based on the hypothesis of the various climates.

The first table, No. XII., shows the coefficients of transparency corresponding to the annual average for four different climates.

The first climate comprises, by way of analogy, the North of France and the southern section of England, Belgium, the North of Germany, and in a general way Central Europe.

The values of the transparency coefficient are indicated for four different totals of the probability. Thus, during 10 per cent. of the year, that is, approximately thirty-six days, it may be stated that the coefficient of transparency will attain at least 0·959, this value being always brought back to the kilometre. This means that, for at least thirty-six days in the year, the atmosphere will be sufficiently clear to allow the passage per kilometre of 0·959 of the luminous flux it receives.

A second value relates to a probability of 50 per cent. The hypothesis may therefore be taken that, on an average, one day out of two the atmosphere will be sufficiently clear to permit the passage per kilometre of 0·900 of the incidental light.

The third coefficient is given for 70 per cent. of the year and the last for 90 per cent. of the year.

This last coefficient therefore means that when the average probability is equal to at least nine days out of ten, the atmosphere will be sufficiently transparent to allow the passage per kilometre of 0·670 of the incidental light.

It is well understood that such coefficients represent hypothetical average values. Thus it may well happen that

for a continued period of bad weather the atmosphere may be opaque during several consecutive days. The same naturally applies to periods during which the atmosphere is clear.

The coefficients in question are represented in order of

TABLE XII.—COEFFICIENTS OF TRANSPARENCY (ANNUAL AVERAGE).

Climates.	Totals of the Probability.			
	10 per cent. of the Year.	50 per cent. of the Year.	70 per cent. of the Year.	90 per cent. of the Year.
	Values of the Coefficient a.			
No. 1. North of France, England, Belgium, North of Germany, Central Europe .	0·959	0·900	0·869	0·679
No. 2. Brittany, Normandy to the east and the Loire, Switzerland, Southern Germany, Central Russia	0·959	0·910	0·862	0·700
No. 3. South-West France, Austria, the Balkans . .	0·959	0·918	0·884	0·750
No. 4. Mediterranean climate, South of France, Italy, Spain, Greece . . .	0·961	0·932	0·926	0·885

importance, and which it is necessary to be able to interpret.

The same table has been worked out for three other climates.

The climate called No. 2 refers to Brittany, Normandy, and a strip of French territory starting from these two provinces to the eastern frontier and the Loire. It also includes, by way of analogy, Switzerland, in its average altitudes, Southern Germany, and Central Russia.

Climate No. 3 comprises the South-West of France, that is, the provinces which border the Atlantic Ocean, and by way of analogy one may include for Europe, Austria, and the Balkans.

Climate No. 4 is that of the basin of the Mediterranean, South of France, Italy, Spain, Greece. The atmospheric transparency is there considerably higher than in the other European climates under consideration.

TABLE XIII.—AVERAGES PER SEASON OF THE TRANSPARENCY COEFFICIENT IN CONTINENTAL FRANCE, BELGIUM, THE SOUTH OF ENGLAND, AND THE CENTRE OF GERMANY.

Seasons.	Totals of the Probability.			
	10 per cent. of the Season.	50 per cent. of the Season.	70 per cent. of the Season.	90 per cent. of the Season.
	Values of the Coefficient a.			
Spring	0·965	0·911	0·871	0·740
Summer	0·965	0·913	0·877	0·766
Autumn	0·958	0·917	0·878	0·727
Winter	0·938	0·889	0·807	0·320

In Table XIII. is given the coefficient of average transparency per season for a combined climate including continental France, Belgium, the South of England, and the centre of Germany.

It will be noticed in this table that at the total of probability of 50 per cent. autumn shows the greatest transparency.

This remark is somewhat contrary to what may be commonly assumed.

Table XIV. shows for the four climates indicated in Table XII. the value of the transparency coefficient in winter. It is immediately seen to what an extent the

TABLE XIV.—COEFFICIENTS OF TRANSPARENCY IN WINTER.

Climates.	Totals of the Probability.			
	10 per cent. of the Season.	50 per cent. of the Season.	70 per cent. of the Season.	90 per cent. of the Season.
	Values of the Coefficient a.			
No. 1. North of France, England, Belgium, North of Germany, Central Europe .	0·951	0·860	0·774	0·234
No. 2. Brittany, Normandy to the east to the Loire, Switzerland, the South of Germany, Central Russia	0·960	0·897	0·833	0·468
No. 3. South-West France, Austria, the Balkans . .	0·960	0·892	0·810	0·234
No. 4. Mediterranean climate, South of France, Italy, Spain, Greece . . .	0·965	0·929	0·917	0·879

TABLE XV.—ANNUAL AVERAGE COEFFICIENTS OF TRANSPARENCY FOR THE DEFINITION OF THE STATE OF THE ATMOSPHERE.

Climates.	Weather.		
	Misty. 90 per cent. of the Year.	Average. 50 per cent. of the Year.	Clear. 10 per cent. of the Year.
No. 1	0·644	0·900	0·962
No. 2	0·679	0·911	0·962
No. 3	0·721	0·917	0·962
No. 4	0·879	0·932	0·964

Mediterranean climate is in this respect superior to the other three under consideration.

Finally, in Table XV. is indicated the average annual

coefficients of transparency for the four above-mentioned climates, corresponding to the definition of the weather which sailors are in the habit of giving.

The weather termed "clear" refers mainly to a probability of 10 per cent., the weather termed "average" of 50 per cent., and "misty weather" of 90 per cent.

During ordinary observations with searchlights, the last coefficients are those which will be of the greatest service. It is clear that what is termed "misty weather" does not consist in a visible mist, because, as soon as there is a fog or visible mist the coefficient of transparency falls to a very low value, and, as previously stated, it is no longer the kilometre which must be taken as the unit, but the hectometre, the decametre, and even the metre.

In the preceding tables mountainous climates have been omitted. In high altitudes the transparency is considerable and equal to that of desert countries; it may be stated, according to observations we have made, that in dry weather free from snow and in the mountains the coefficient of transparency rises to

$$a = 0{\cdot}940$$

In winter when there is snow the dryness is almost absolute, and with the added effect of contrast, the coefficient may be valued at a minimum of

$$a = 0{\cdot}970$$

These values appear to correspond to a probability of at least 50 per cent.

Some carefully observed tests on the use of searchlights in mountainous districts have proved that the range is considerably greater than in level countries, or in countries with an average altitude.

The French Administration for Lighthouses, which was the first to determine the values of the coefficient on the coasts of France (we have previously mentioned the works of M. Allard), now only indicate for the illumination of the coasts, ranges which correspond to two totals of the probability, *i.e.*, 50 per cent. and 90 per cent., of the year.

As regards searchlights, we might have limited to these totals the calculated values of the ranges and illumination, but it was thought that it would be more instructive, when calculating various other points, to also give the general form of the curves for each of the cases under consideration. It would be well, of course, not to attach too much importance to these calculations, which are based on the hypotheses which it has been necessary to assume for the coefficients of transparency in land climates, and which can only be confirmed from actual experiences and tests.

CHAPTER VII

PRACTICAL APPLICATION OF THE LAW OF RANGES, APART FROM THE VISUAL ACUITY

GRAPHIC DIAGRAM TO DETERMINE THE VALUE OF THE QUOTIENT $\frac{a^{l+l'}}{(l)^2}$.—The determination of the quotient $\frac{\epsilon_o}{\epsilon_p} = \frac{a^{l+l'}}{(l)^2}$ always requires long and tedious calculations. The numerator comprises, in fact, a coefficient smaller than the unit, which must be raised to variable powers, mostly fractional, seeing that the unit chosen is the kilometre. It would not take as long to calculate the denominator, but the whole of the quotient, which is always a quantity considerably less than the unit, necessitates a laborious calculation.

In order to facilitate the calculation a number of diagrams are given, the reading of which is fairly convenient, thereby enabling the rapid solution of any problems in connection with the ranges of electric light projectors, apart from the visual acuity or sharpness.

FIRST DIAGRAM: SIMPLIFIED FORMULA (Fig. 8).—The first diagram has been drawn for the simplified formula (27), in which the distance from the searchlight to the object is equal to that from the observer to the object, that is, where $l = l'$.

$$\epsilon_o = \epsilon_p \frac{a^{2l}}{l^2} j$$

The notion of the equivalent illumination has enabled us

in this formula to make $j = 1$; it therefore becomes simplified as

$$\epsilon_o = \epsilon_p \frac{a^{2l}}{l^2}$$

From this expression one can write

$$\frac{\epsilon_o}{\epsilon_p} = \frac{a^{2l}}{l^2}$$

Then, taking the logarithms of the two numbers, there results

$$\log\left(\frac{\epsilon_o}{\epsilon_p}\right) = \log\left(\frac{a^{2l}}{l^2}\right) = \log(a^{2l}) \log(l^2)$$

However, as

$$\frac{\epsilon_o}{\epsilon_p} < 1$$

and in order not to have any negative logarithm, we write

$$-\log\left(\frac{\epsilon_o}{\epsilon_p}\right) = 2\log(l) - 2l\log(a) = 2\log(l) + 2l\log(-a).$$

Assuming now that

$$-\log\left(\frac{\epsilon_o}{\epsilon_p}\right) = y \qquad l = z \text{ and } \log(-a) = x$$

we finally arrive at the equation :

$$y = 2\log(z) + 2zx$$

This equation is that of a topographical surface having three dimensions x, y, z.

Its intersection by the planes xy (for each value of $z =$ a constant), gives straight lines represented by the equation

$$y = 2\log(l) + 2lx$$

The abscissæ are therefore values of x or of $\log(-a)$.

The ordinates are the logarithms of $\frac{\epsilon_o}{\epsilon_p}$ with the minus sign.

The scale of the abscissæ must be drawn up in such a manner as to render the diagram as adaptable as possible.

The scale of the ordinates has been chosen so that the unit represents one million lux or P = one million decimal candle-power at a distance of 1 metre from the searchlight. The same illumination therefore corresponds at a distance of 1,000 metres to the value of 1 lux. It is therefore easy, knowing the value of ϵ_p, which is given at 1,000 metres, to immediately obtain the ratio $\frac{\epsilon_o}{\epsilon_p} = \frac{a^{2l}}{l^2}$ by dividing the number in the ordinates, which corresponds to $\epsilon_p = \mathrm{I}$, by the value of the practical illumination of the searchlight under consideration.

By way of example, let it be assumed that a searchlight giving a practical illumination of $\epsilon_p = 20$ lux is placed in a position for the observation of an object, the equivalent illumination ϵ_o of which is equal to 0·5 lux.

The value of the ratio $\frac{\epsilon_o}{\epsilon_p}$ will therefore be $\frac{0{\cdot}5}{20} = 0{\cdot}025$.

Given this value, the question will be asked, what will be the range of the searchlight with a coefficient of transparency of 0·891. The diagram immediately indicates a range of approximately 4 kilometres. It is sufficient for the purpose to read in the column of the ordinates the number 0·025, and on that of the abscissæ the value 0·891. These two straight lines cut each other practically at the 4 kilometre line.

An examination of the whole of this diagram will show to what extent the ratio $\frac{\epsilon_o}{\epsilon_p}$ must decrease in proportion as

the ranges increase; that is, for the same equivalent illumination ϵ_o, the practical illumination ϵ_p must increase for a comparatively slight diminution of the coefficient of transparency. In effect, the straight lines of range in the diagram incline more and more rapidly towards the bottom of the diagram as they approach the larger ranges.

SECOND DIAGRAM: SIMPLIFIED FORMULA (Fig. 9).—In certain cases the second diagram is more convenient.[1]

In order to apply it the general method of plotting by points set in a line, as indicated by M. Maurice d'Ocagne, is adopted.

The value of the ratio $\frac{\epsilon_o}{\epsilon_p}$ is read on the horizontal line, which occupies the upper part of the diagram. The values of the coefficient of transparency a are indicated on the lower horizontal line.

In order to read the diagram it is sufficient to make use of a movable ruler. For instance, if a coefficient of transparency and the value $\frac{\epsilon_o}{\epsilon_p}$ are given, the ruler must be made to correspond to two points on the two horizontal lines of the top and bottom of the diagram, and the intersection on the intermediary curve will correspond to the range in kilometres.

Inversely, if the coefficient of transparency and the range in kilometres are given by joining these two points the ruler will cover a point on the upper horizontal line and will give the value of $\frac{\epsilon_o}{\epsilon_p}$.

If ϵ_o is known, ϵ_p will be deducted therefrom, and, inversely, if ϵ_p is known, ϵ_o will be deducted.

[1] This modification of the original diagram has been proposed to us by M. Batifoulier, engineer of the firm of Harlé & Co., as well as diagram in Fig. 10.

THIRD DIAGRAM: COMPLETE FORMULA (Fig. 10).—The complete formula (26) applies to the general problem in which the distances l and l' are not equal. In this formula, if j equals the unit, it will be found that

$$\frac{\epsilon_o}{\epsilon_p} = \frac{a^{l+l'}}{(l)^2}$$

The diagram No. 3, Fig. 10, makes it possible to immediately solve by a simple graphic reading all the problems which relate to the general formula for ranges.

This diagram is entirely analogous to that of Fig. 9 for the simplified formula, but it includes the drawing of several curves of ranges. A special curve corresponds to the case where $l' = l$. It is the same curve as that of Fig. 1. This curve is between two other series of curves, one corresponding to the values of the ratio $\frac{l'}{l} > 1$, and the other to the values $\frac{l'}{l} < 1$.

We have chosen as values of these ratios: 1·25 — 1·50 — 1·75 — 2·00, then 0·75 — 0·50 — 0·25 and 0.

It is easy, by tracing the transverse lines as in the diagram in Fig. 9, to cut the intermediate points between the limits given.

All the curves traced refer to the value of the range l from the searchlight to the objective; l' is deduced therefrom by the value of the ratio $\frac{l'}{l}$.

From an examination of this diagram it is possible to immediately solve the following problem.

GENERAL PROBLEM OF RANGES.—If a searchlight and an observer are placed at the same distance from an illuminated

object, and if it is desired to increase the visibility of the object, is there a greater advantage in bringing the searchlight nearer to the object or the observer nearer to the object ?

This case is that shown in Fig. 7 by the sketches (*a*), (*b*) and (*c*).

In the sketch (*a*), the two distances are equal $l' = l$.

In (*b*), l is shorter than l'. In (*c*), l is longer than l'.

Let it be assumed that a searchlight giving a practica illumination $\epsilon_p = 37$ lux illuminates an object corresponding to an equivalent illumination $\epsilon_o = 0{\cdot}5$ lux with an atmospheric transparency of $a = 0{\cdot}900$, and that $l' = l = 5$ kilometres, the two distances being equal.

Assume also that, under the conditions of this experiment, it is found that the object illuminated is not sufficiently visible, and that it is proposed either to bring the searchlight 2 kilometres nearer to the object, which will make $l = 3$ kilometres, and $l' = 5$ kilometres, which means a total path of 8 kilometres for the luminous rays. Alternatively the observer can advance 2 kilometres nearer to the object, which will make $l = 5$ kilometres, and $l' = 3$ kilometres, the total path $l' + l = 8$ kilometres.

By taking the searchlight nearer, one will therefore obtain $\frac{l'}{l} = \frac{5}{3} = 1{\cdot}666$ and by advancing the object $\frac{l'}{l} = \frac{3}{5} = 0{\cdot}60$.

The value of the ratio $\frac{\epsilon_o}{\epsilon_p}$, which was originally 0·0135 for $l' = l$, becomes equal in the first case to 0·0465, whereas in the second case it only amounts to 0·0168.

It will be seen immediately that, for the same total path of the luminous rays, the fact of bringing the searchlight 2 kilometres nearer corresponds to an increase in the illumination of $\frac{465}{168} = 2{\cdot}77$ times the illumination which would

be obtained by causing the observer to advance 2 kilometres, the searchlight remaining stationary.

Therefore, each time that it is possible to bring the searchlight nearer to the object, considerably more will be gained than by bringing the observer a similar distance nearer to the object.

The diagram in Fig. 10 makes it possible to generalise the preceding problem.

Supposing that it is desired to find the ranges of a searchlight, being acquainted with the transparency coefficient, the equivalent illumination of a specified object, and the practical illumination of the particular searchlight employed.

Seeing that the group of curves for the range in the general diagram always refers to the distance l between the searchlight and the object, it is possible for a predetermined distance to calculate the distance l' at which the observer must place himself in order to see the specified object, under the indicated conditions of transparency and illumination.

If the ratio $\frac{l'}{l}$ is chosen equal, for instance to 1·5—*i.e.*, that the distance between the observer and the object is to be 50 per cent. greater than that between the object and the searchlight—it is possible to immediately find from the curves in question the two values l and l'. In order to obtain this, it is necessary to determine the point of intersection of the straight line which joins the value of the coefficient of transparency to the value of the ratio $\frac{\epsilon_o}{\epsilon_p}$ with the curve corresponding to the ratio $\frac{l'}{l} = 1{\cdot}5$. This point of intersection immediately shows the value of the range l, from which is deduced l', by the proportion $l' = l \times 1{\cdot}5$.

Let us take an example :

$$a = 0{\cdot}9$$

$$\frac{\epsilon_o}{\epsilon_p} = 0{\cdot}025$$

The intersection of this straight line with the curve $\frac{l'}{l} = 1{\cdot}5$ corresponds to the range $l = 3{,}800$.

The result is that $l' = 1{\cdot}5 \times 3{,}800 = 5{,}700$ metres.

If, therefore, the searchlight in question is placed at a distance of 3,800 metres from the object, it will be possible for the observer to withdraw to a distance of 5,700 metres and still have a suitable and convenient illumination.

Under similar conditions of transparency, with the same searchlight and the same object, the curve immediately indicates that if $l' = l$, these two distances being equal, the range is 4,050 metres.

It is therefore seen that by bringing the searchlight 250 metres nearer to the object it will be possible to place the observer 1,650 metres further away.

With this curve, which is very convenient, it is possible to rapidly solve all inverse problems.

Thus, for a given coefficient of transparency, admitting that the distance of a searchlight to an object is fixed and that the position of the observer is also known, it is possible to determine the practical illumination ϵ_p which the searchlight must give, and consequently its diameter for a known equivalent illumination ϵ_o. In fact, knowing the figurative point on the curve of ranges and the point of the scale of transparencies, the straight line which joins them again cuts the upper scale of the drawing at a point which indicates the value of the ratio $\frac{\epsilon_o}{\epsilon_p}$.

If the value ϵ_o is known, ϵ_p can be deduced from it. Inversely, having particulars of the searchlight and the

range and also the coefficient of transparency, the diagram will give the value of ϵ_0.

It is therefore possible to know at once what are the objects which it is possible to illuminate at the distance in question, as well as those which it will not be possible to illuminate, that is, those whose equivalent illumination will be higher than what it is possible to obtain.

It would also be possible to solve another problem, and to determine the coefficients of transparency which are necessary for the illumination of a specified object at ranges which are also specified. Briefly, the curve in question can be quite generally applied for the study of any problems which may arise during the tactical use of searchlights, always apart from the influence of visual acuity or sharpness.

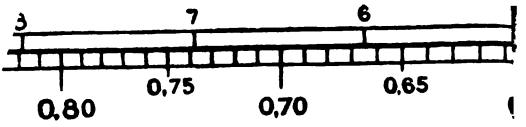
Determination of Equivalent Illuminations.—It has been previously stated that the only procedure by which is made possible the practical utilisation of the range of searchlights, consists in predetermining the value of the equivalent illuminations corresponding to well-defined objects.

The method followed for the attainment of this result consists in a careful analysis of all the tests carried out with searchlights, where it has been possible to obtain accurate and reliable data.

The first detailed experiments date back to the year 1877, when a lense form of searchlight 0·60 metre in diameter was tested on board the *Richelieu*, of the French Navy, in the Mediterranean.

During the Russo-Turkish War a Mangin searchlight of 0·90 metre was used on the Russian coast of the Black Sea.

In 1879, methodical trials were undertaken at Pola, with the assistance of Mangin searchlights having diameters of 0·30 metre and 0·60 metre, on steam launches, vessels, forts, and various buildings.


7
6
0,80
0,75
0,70
0,65

During the same year other tests were carried out at Portsmouth.

Comparative experiments, far more complete, were then undertaken at Chatham in 1879 and 1881, with the assistance of Mangin searchlights of 0·60 metre diameter and prismatic lenses.

In 1887 and 1888, during their Abyssinian campaign, the Italians employed Schuckert searchlights 0·90 metre in diameter.

Also in 1888 comparative searchlight tests were carried out at Antwerp between Schuckert searchlights having a diameter of 0·90 metre and Mangin searchlights of 0·65 metre and 0·90 metre. These tests were controlled by a Military Commission and were carefully carried out, with the result that the observations made can be accepted with every confidence.

During the same year searchlight tests were carried out in Paris, at the Sautter-Harlé Works, with searchlights of 0·90 metre, and at Nuremberg, at the Schuckert Works, with 0·60 metre and 0·90 metre searchlights.

In 1891 comparative tests were obtained in Turkey between Mangin searchlights and Schuckert searchlights. These experiments made it possible to determine the value of the coefficient of transparency in that country, because until then no data of the kind was in existence there.

During the same year the Spanish Army carried out at Carabanchel, near Madrid, a series of tests with Mangin searchlights of 0·90 metre. These experiments occurred during the winter and showed the remarkably high degree of atmospheric transparency of this region due to the dryness of the air.

In 1892 tests were carried out at the Eiffel Tower with 0·90 metre searchlights. The height of the tower made it possible to obtain accurate results which could be readily supervised and confirmed.

In 1893 the French Army undertook experiments at the Mont-Valérien with searchlights of 0·60 metre and of 0·75 metre.

Other military experiments were also carried out at the Vaujours Fort in 1894.

About the same period comparative trials were obtained at Toulon in 1895 by the French Navy, under the direction of a Military Commission, on Mangin searchlights and Schuckert searchlights 0·60 metre and 0·90 metre in diameter; the results obtained were absolutely in accordance and agreed with similar previous tests.

In 1896 the French Navy carried out further experiments at Brest on Mangin searchlights of 0·90 metre having a short focus.

Other trials were carried out in Spain in 1898 at the port of Cadiz which are of interest.

The following are the most important experiments on searchlights up to the present time.

In 1899 at Marseilles on marine objects with 1·20 metre searchlights installed at special photo-electrical positions along the coast.

In 1901 at Calais with coast searchlights.

The same year in Holland at the port of Huisdinen.

In 1903 comparative tests in Switzerland under the supervision of the Federal Army, at the fort of Dailly, with searchlights having diameters of 0·90 metre, 1·10 metres, and 1·20 metres.

In 1908 a Government Commission carried out very important trials at Cherbourg and Havre with coast defence searchlights. A comparison was made between Mangin searchlights of 0·90 metre, 1·20 metres, and 1·50 metres, and with parabolic glass mirrors of 0·90 metre and 1·50 metres; and finally with gilded parabolic metallic mirrors.

In 1909 the Swedish Artillery obtained a series of com-

parative tests on a searchlight with a diameter of 1·10 metres and a parabolic glass mirror, also with a gilded metal mirror, for the purpose of illuminating the approaches of the Boden Fortress, on the frontier of Finland. These tests were of a most interesting character, because the country was covered with snow, and every facility was available for directing the firing with large cannon.

In 1911 the Belgian military engineers obtained some very complete tests at the Beverloo Camp in comparison with a Schuckert searchlight having a silvered glass mirror of 0·90 metre and a Sautter-Harlé searchlight having a gilded parabolic mirror of the same size.

In 1905 a squadron of the French Fleet obtained comparative tests between searchlights of 0·75 metre with glass mirrors and searchlights with gilded parabolic mirrors of the same size.

In 1910 an artillery corps of the Russian Army at Cronstadt obtained comparative tests between a searchlight of 0·90 metre with a gilded metallic mirror and a Schuckert searchlight with a parabolic glass mirror.

A similar series of tests were also carried out on the Bosphorus, in Turkey, in December, 1906.

Finally, the French Navy organised at Toulon, at the commencement of 1914, a series of detailed tests with Mangin mirrors and gilded parabolic metallic mirrors of 0·90 metre and 1·50 metres and with various focal lengths. These important tests have been carefully controlled, and the numerical results merit every confidence being placed in them.

It has been possible to analyse the large amount of numerical data resulting from these varied experiments.

The comparative tests of searchlights having different diameters and focal lengths are specially useful for the determination of the equivalent illuminations. When, for instance, it is ascertained that two apparatus yield the

same visibility at different ranges, and if it is possible to calculate their practical illumination, it becomes easy, with the help of a few assumptions concerning the atmospheric transparency at the time of the experiment, to

TABLE XVI.—EQUIVALENT ILLUMINATIONS ϵ_0.

	Limit of Visibility.		Visibility of Details.	
	With Glasses.	With the Naked Eye.	With Glasses.	With the Naked Eye.
	Lux.	Lux.	Lux.	Lux.
Land Objectives.				
Group of infantry on dark background	8·50	6·00	—	—
Troop of infantry in dark uniforms	1·80	—	—	—
Body of cavalry on dark background	1·40	—	—	—
Troop of infantry on snowy background	—	1·50	—	—
Large mass of infantry on snowy background	—	1·00	—	—
A fort of permanent structure on dark background	0·23	—	0·45	—
Large, light-coloured building, hospital, barracks, fort, etc.	—	—	0·20	0·84
Light grey church and steeple	—	—	0·28	—
A village, a bridge, and a crossing of roads	0·27	0·37	0·50	—
Marine Objectives.				
A modern armoured warship	0·23	—	—	—
A dark-coloured torpedo-boat	0·70	—	1·00	—
A boat with dark sails	0·60	—	—	—
A red buoy	1·00	—	—	—
A black buoy	4·80	—	—	—
A submarine turret	5·00	—	—	—

determine the equivalent illumination. This illumination must necessarily be the same for the two apparatus, seeing

that it applies to the same object. It is therefore possible with the aid of the curve and the values chosen for the coefficient of transparency to arrive at the same value of a for the two apparatus. This inverse method is easy of application and has enabled us to determine the equivalent illumination, which varies slightly according to the experiments, taking into account the errors of observation and also the effect of the visual sharpness, which we are unable to calculate, introduces an additional error. The approximate agreement of similar determinations may be considered as satisfactory for practical calculations.

In Table XVI. is given the average value of the equivalent illuminations for a whole series of land and marine objectives. These values are given both for sight with the naked eye and with use of field-glasses. They apply either to the limit of visibility, that is, the distance at which it is possible to perceive the whole of the objects with sufficient precision to permit the direction of firing or to the visibility of the details, which naturally corresponds to a higher equivalent illumination. In this table many divisions have remained blank for want of observations, but the values obtained render it possible to calculate with sufficient exactness for ordinary practical purposes, especially if it is not desired to obtain extreme values for short or very long ranges.

When examining these values, it will be especially noticed that in the case of objects of small dimensions, such as an infantryman or a group of infantry, a horseman, or with objects on the sea, a small boat, a buoy, or the turret of a submarine, the value of the equivalent illumination greatly increases. In fact, as soon as an object subtends an arc with an angle of 3 or 4 minutes it approaches the limit at which the human eye ceases to perceive the details; the necessary illumination then increases to a very large extent, owing to the phenomenon of the visual sharpness.

In order to clearly distinguish the object at a distance it becomes necessary to make use of field-glasses, or some other similar optical device.

A well-designed field-glass magnifies in practice by five or six diameters, with a loss of light of 15 to 20 per cent. It is therefore possible to distinguish an object of small dimensions by giving to the eye a sharpness which it would not possess when viewing with the naked eye. M. Blondel has recently given a general law for ranges, taking into account the visual sharpness, which will be referred to later. Unfortunately the determination of the coefficients which enter into the formulæ would require numerous experiments carried out under the most varied conditions occurring in practice, but which have not up to the present been obtainable.

It is needless to say that the equivalent illuminations shown in Table XVI. are average values, the same object not always corresponding to the same illumination, according as to whether it stands out from a light or a dark background. In a general way, however, this series of tests will make it possible to obtain, with a reasonable approximation, the degree of the importance of the ranges of various projectors and the different objects illuminated.

In order to get an idea of the value of the equivalent illuminations shown in the preceding table, it will be sufficient to observe that the illumination given by the sun at noon on a clear day over a surface normally exposed to the direction of the luminous rays is equal to 160,000 lux; whereas the value of the illumination given by the moon, when full and passing the meridian, is approximately of 0·2 lux.

The illumination of public highways in large modern towns frequently attains 5 and even 6 lux, but for town suburbs a far lower illumination would be sufficient.

CHAPTER VIII

EXAMPLES AND PRACTICAL PROBLEMS OF RANGES

THE considerations which have been elaborated in the preceding chapters respecting the calculation of the illumination of searchlights, and also of the general formula of ranges, together with the analysis of the various elements apart from the visual sharpness, would not be complete if not accompanied by examples and the results which it is possible to obtain with the aid of the preceding information in calculating either of the ranges attainable with a given searchlight, or the luminous power necessary to attain a specified range.

DETERMINATION OF THE PRACTICAL ILLUMINATION OF A SEARCHLIGHT, WHERE THE RANGE FOR A SPECIFIED OBJECTIVE IS KNOWN, AND ALSO THE COEFFICIENT OF TRANSPARENCY.

LAND OBJECTIVES.—(1) *Visibility of a Fort or of a Permanent Structure standing out from a Dark Background, the Distances l and l′ being Equal.*—In Fig. 11 is shown the curves of practical illumination ϵ_p, corresponding to the visibility of a fort or of a permanent structure, standing out from a dark background, at a range of 3,000 metres.

These curves refer to the climate at the North of France in autumn (see Table XIII., giving the value of the coefficients of transparency).

The first curve indicates the limit of visibility of the objective; it corresponds to an equivalent illumination of 0·23 lux (Table XVI.).

The second curve refers to the distinct visibility of the details, which corresponds to an equivalent illumination of 0·45 lux.

In these curves the abscissæ represent the value of the probability, which is itself a function of the coefficient of

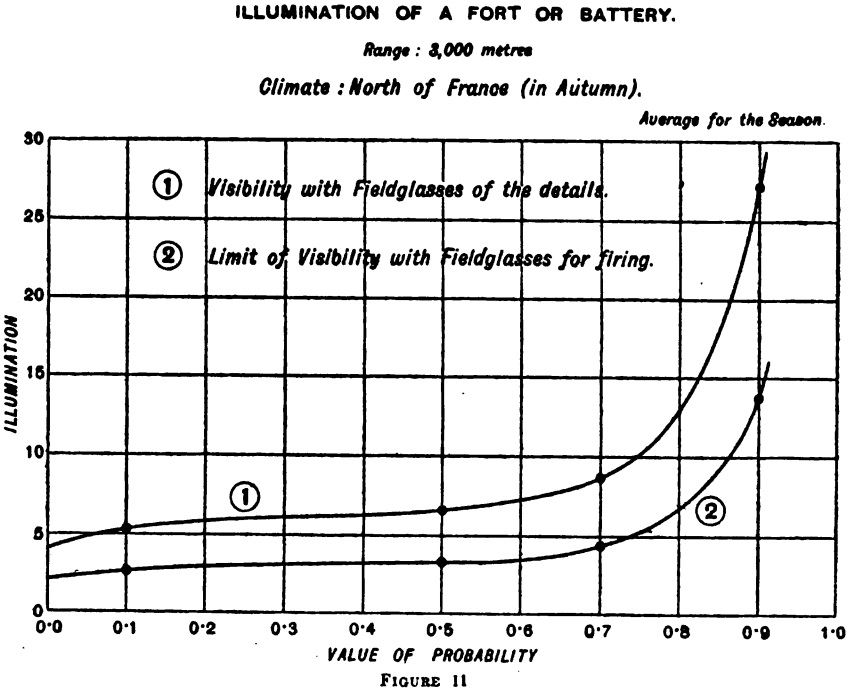


FIGURE 11

transparency, as is seen in Table XIII. The two curves have been traced with the aid of four values calculated for the totals of probability of 1/10, 5/10, 7/10 and 9/10.

With the aid of the curve in Fig. 9 it becomes an easy matter to calculate the corresponding illuminations. For instance, it is found that for the limit of visibility the average probability of 1/10 in autumn (*i.e.*, one day out of ten) will be reached if the searchlight gives a practical illumination ϵ_p of 2·67 lux. In order to be certain to observe

the objective five days out of ten, 3·43 lux will be required; seven days out of ten, 4·42 lux; nine days out of ten, 13·85 lux.

For a good visibility of the details, the corresponding numbers will be :—

1/10, 5·23 lux
5/10, 6·72 „
7/10, 8·65 „
9/10, 27·10 „

With the help of these curves, according to the value of the probability it is intended to obtain, the corresponding size of searchlight will have to be chosen.

For instance, in the case of searchlights without flashing shutters, it will immediately be seen that in order to be certain under the above-mentioned conditions and at the limit of visibility to succeed, five days out of ten, it will be sufficient, with low voltage carbons and a focal length of 40 per cent. of the diameter, to use a searchlight of 0·40 metre (Table VI.).

If on the contrary it is desired to obtain a probability of 7/10, *i.e.*, the certainty of seeing the object seven days out of ten, with the same focal length, a searchlight provided with flashing shutters will have to be of 0·50 metre diameter.

Finally, if it is desired to illuminate at the limit of visibility nine days out of ten, it will be necessary, with flashing shutters, to have a searchlight 0·75 metre in diameter.

These sizes might be reduced if the mirrors were of long focal lengths, and 0·60 metre would then be sufficient instead of 0·75 metre. The width of the illuminated zone would, however, be less, as is shown in Table IV.

If on the contrary high voltage carbons are used, a more powerful illumination will be obtained for the same size,

and Table VI. will show what mirror diameter must be used.

It will be noticed how rapidly the necessary illumination increases as the value of the probability increases, that is, as the average coefficient of transparency is reduced.

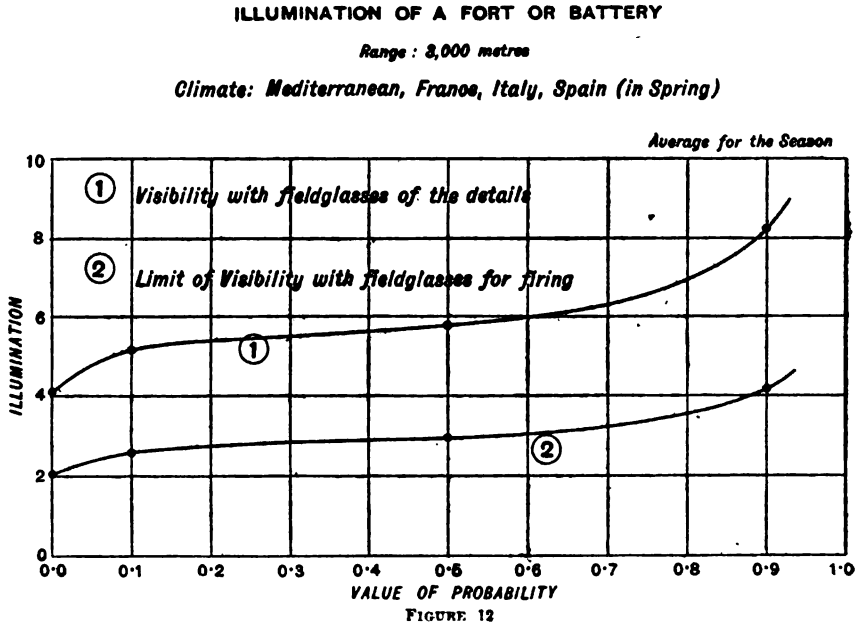


FIGURE 12

Thus, in order to obtain a good visibility of the objective, and if it is desired to illuminate nine days out of ten, a searchlight is necessary of 1·10 metres in diameter and a focal length of 40 per cent. of the mirror diameter or a searchlight 0·90 metre in diameter and a focal length of 60 per cent. of the diameter.

We have made the same calculations in a far more favourable climate—during spring in the Mediterranean, which comprises the South of France, Italy, Spain, etc. (Tables XIV., XV.). The objective and the range remained the

same, and in Fig. 12 will be seen the reduction in the illumination necessary. Thus, for the limit of visibility and for a probability of nine days out of ten, 4·11 lux are sufficient with a 0·50 metre searchlight with flashing shutters. For good visibility of details 8·04 lux is sufficient with a 0·60 metre searchlight with flashing shutters and the same focal length.

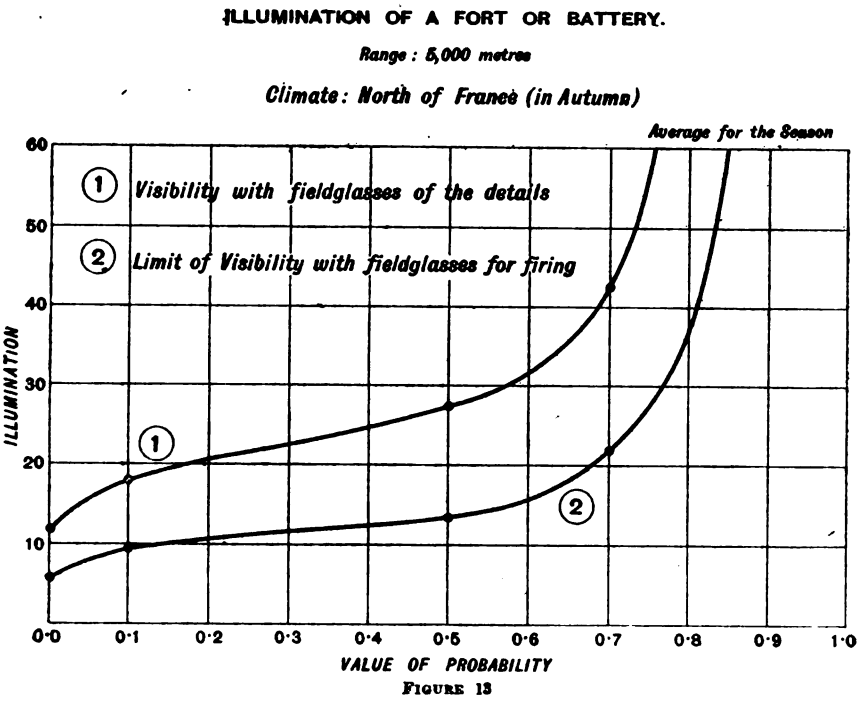


FIGURE 13

It is of interest to work out similar calculations for the same object and for the two climates considered, but for a range of 5,000 metres.

As regards the Climate No. 1 (North of France), we have indicated the analogous curves in Fig. 13. It will be seen that the limit of visibility for the probability value of nine days out of ten, requires the high illumination of 139·30 lux, that is, the use of a 2 metre searchlight without flashing shutters with high voltage carbons and a focal length of 40 per cent. of the mirror diameter.

For a good visibility of the details it would not be possible to obtain a probability value of 9/10, because the necessary practical illumination would attain 272·70 lux, which would necessitate a searchlight considerably larger than 2 metres, which is the largest in use up to the present for coast defences with ordinary carbons.

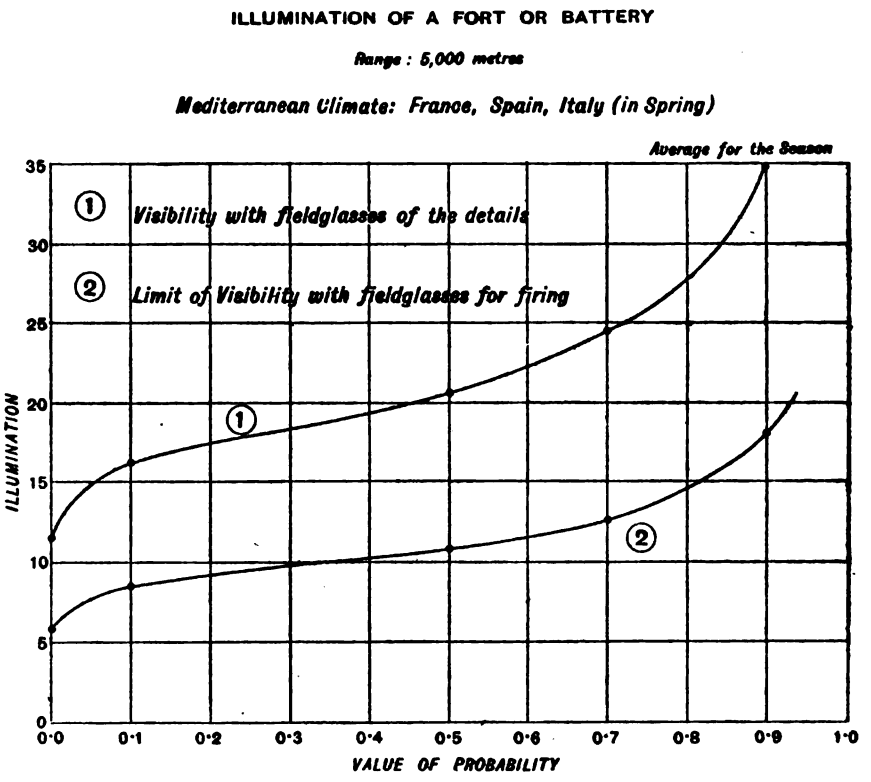


FIGURE 14

The limit of visibility already requires 21·30 lux for a probability of 7/10. This means with low voltage a 0·90 metre searchlight and with high voltage 0·75 metre. With flashing shutters a 0·60 metre searchlight might be used for high voltage, but with a long focal length, consequently with a considerably smaller illuminated field.

In Fig. 14 the corresponding curves are given for the Mediterranean climate. The influence of the transparency will at once be noticed, seeing that it is possible to attain the probability value of 9/10, either for the limit of visibility or for the visibility of details, without being com-

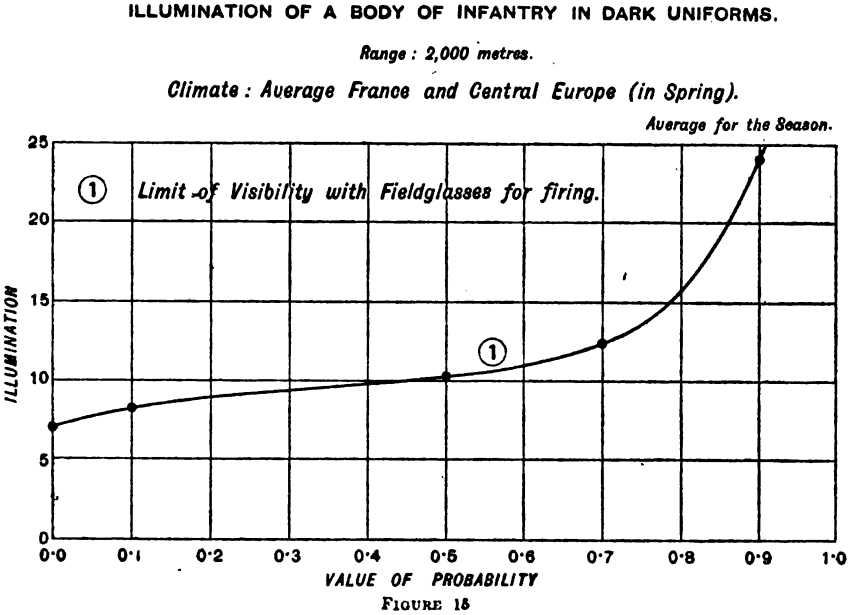


FIGURE 15

pelled to employ abnormal sizes of searchlights. Thus, the limit of visibility requires $\epsilon_p = 17{\cdot}82$ lux, obtainable from a searchlight of 0·75 metre with high voltage, or of 0·90 metre with low voltage; for the visibility of details, 34·86 lux, obtainable from a low voltage 1·20 metre searchlight or from a high voltage 0·90 metre searchlight.

It will be possible in each case to decide from Table VI. on the most suitable searchlight, depending upon its employment either on ships, military field service, fortresses or coast illumination.

(2) *Visibility of a Troop of Infantry with Dark Uniforms.*—

In Fig. 15 is shown the limit of visibility of a troop of infantry for a range of 2,000 metres in spring and a climate corresponding to continental France, Belgium, the South of England and the centre of Germany. (See Table XIII.) As in example No. 1, it is assumed that the observer and the searchlight are at equal distances from the objective, *i.e.*, $l' = l$.

The limit of visibility with field-glasses, when firing at such an objective, corresponds to an equivalent illumination of 1·80 lux. It will be seen that the necessary illumination to attain a value of 7/10 is already 12·40 lux and for a value of 9/10, 24 lux.

In Fig. 16 is shown three curves which also refer to the illumination of foot soldiers standing out from a dark background. The equivalent illumination is 3·5 lux for the limit of visibility with field-glasses and 6 lux for the limit of visibility with the naked eye.

The two upper curves refer to a range of 2,000 metres in the same climate (average for France and Central Europe in spring) as that chosen for the curve in Fig. 15.

The lower curve corresponds to the limit of visibility with the naked eye at a range of 1,500 metres.

It will immediately be seen that a considerable illumination is required for the visibility with the naked eye. Thus at a range of 2,000 metres, no less than 41·35 lux are required to attain the probability of 7/10.

(3) *Visibility of a Troop of Cavalry on a Dark Background,* $l' = l$.—Fig. 17 refers to this example. The equivalent illumination for the limit of visibility with field-glasses is 1·40 lux.

We have assumed a range of 2,000 metres and the same climate as that considered in the preceding example with regard to foot soldiers.

(4) *Visibility of a Large Light-coloured Building, Hospital Barracks, Storehouse, $l' = l$.*—The equivalent illumination for this lighting is 0·34 lux for good visibility of the details with the naked eye, and of 0·20 lux for the same visibility of details but with field-glasses.

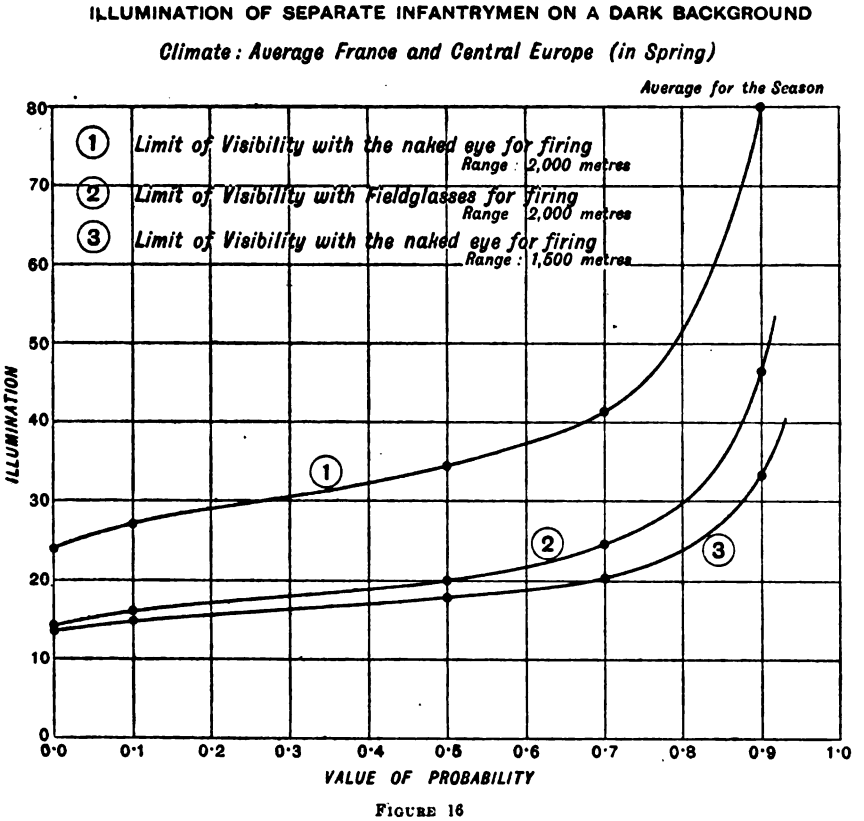


FIGURE 16

These curves have been worked out for a continental climate as an average for France, Belgium, England and Germany in winter (see Table XIII.), and for a range of 5,000 metres.

It will immediately be seen that the visibility of details already requires for a probability of 7/10 with field-glasses 42·1 lux, and for vision with the naked eye, 71·6 lux.

It would therefore be necessary to provide a searchlight from 1·20 metres to 1·50 metres according to the focal lengths and the voltage chosen. (See Table VI.)

(5) *Visibility of a Village, Bridge, and a Crossing of Roads, $l' = l$.*—The curves corresponding to these objectives

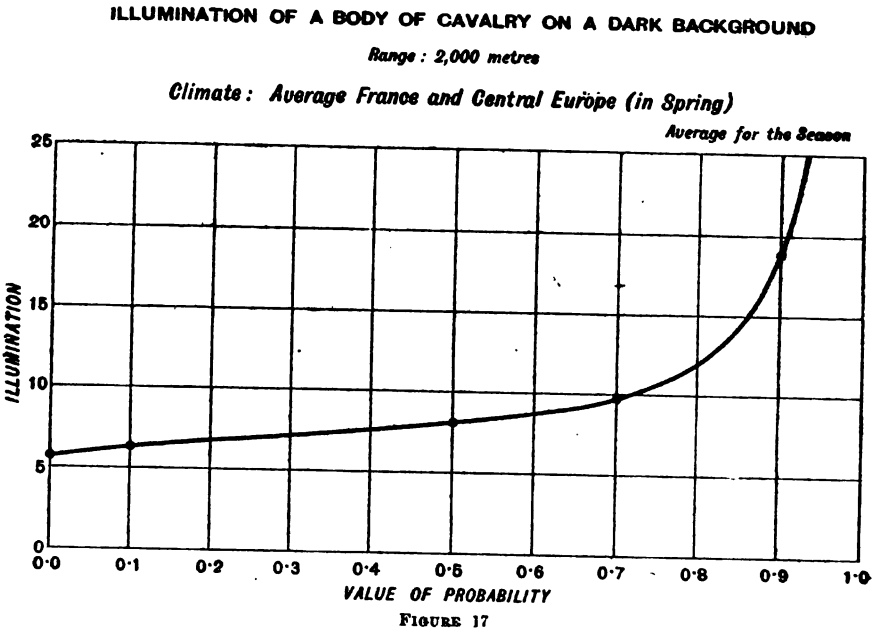


FIGURE 17

are represented in Fig. 19. A range of 3,000 metres is assumed, also that the observer and the searchlight are at equal distances. The climate chosen is the same as that for the preceding example in winter. (See Table XIII.)

The equivalent illumination for the limit of visibility with field-glasses is 0·27 lux, and for the limit of visibility with the naked eye 0·37 lux; for good visibility of details with field-glasses, 0·5 lux.

In the same figure are also given the curves corresponding to the same objective illuminated at a distance of 5,000 metres, but in a good climate, that is, in summer and in the Mediterranean.

ILLUMINATION OF A LARGE BUILDING (light in colour),
HOSPICE, BARRACKS, STOREHOUSE.

Range : 5,000 metres.

Climate : Average France, Belgium, England (in Winter).

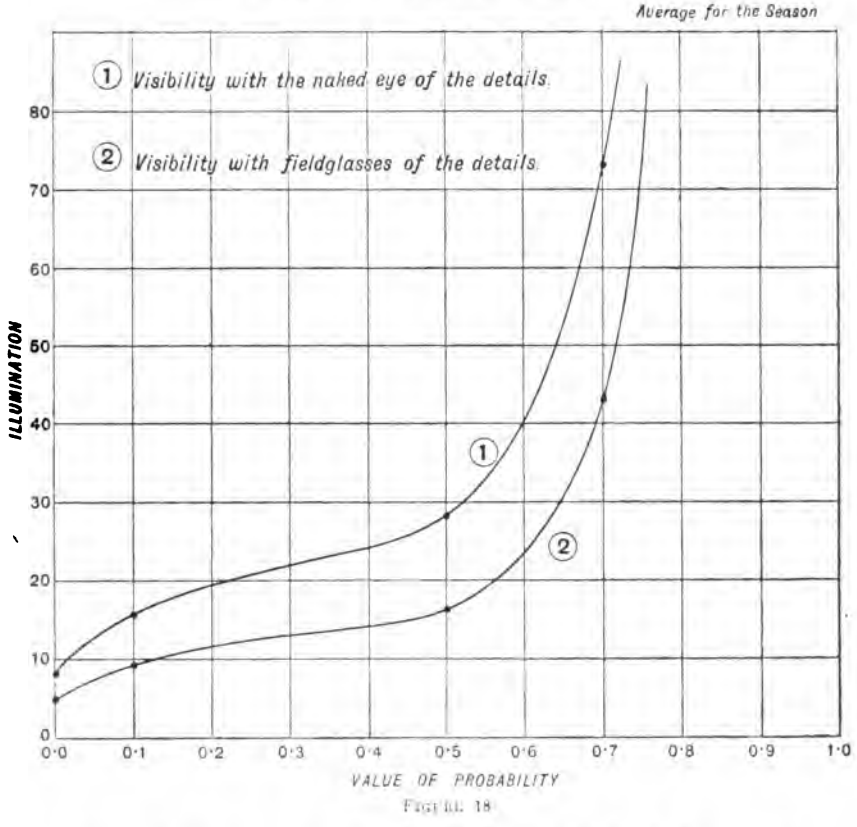


FIGURE 18.

The values of the transparency coefficient in summer for the Mediterranean have not been shown in the preceding tables ; they are as follows :—

VALUES OF THE PROBABILITY.

1/10 = 0·966 in summer in the Mediterranean.
5/10 = 0·939 ,, ,, ,, ,,
7/10 = 0·926 ,, ,, ,, ,,
9/10 = 0·892 ,, ,, ,, ,,

ILLUMINATION OF A VILLAGE, BRIDGE, OR A CROSSING OF ROADS.

Range : 3,000 metres

Climate : Average France, Belgium, England (in Winter).

ILLUMINATION OF THE SAME OBJECTIVE.

Range : 5,000 metres

Climate : Mediterranean, South of France, Italy, Spain (in Summer).

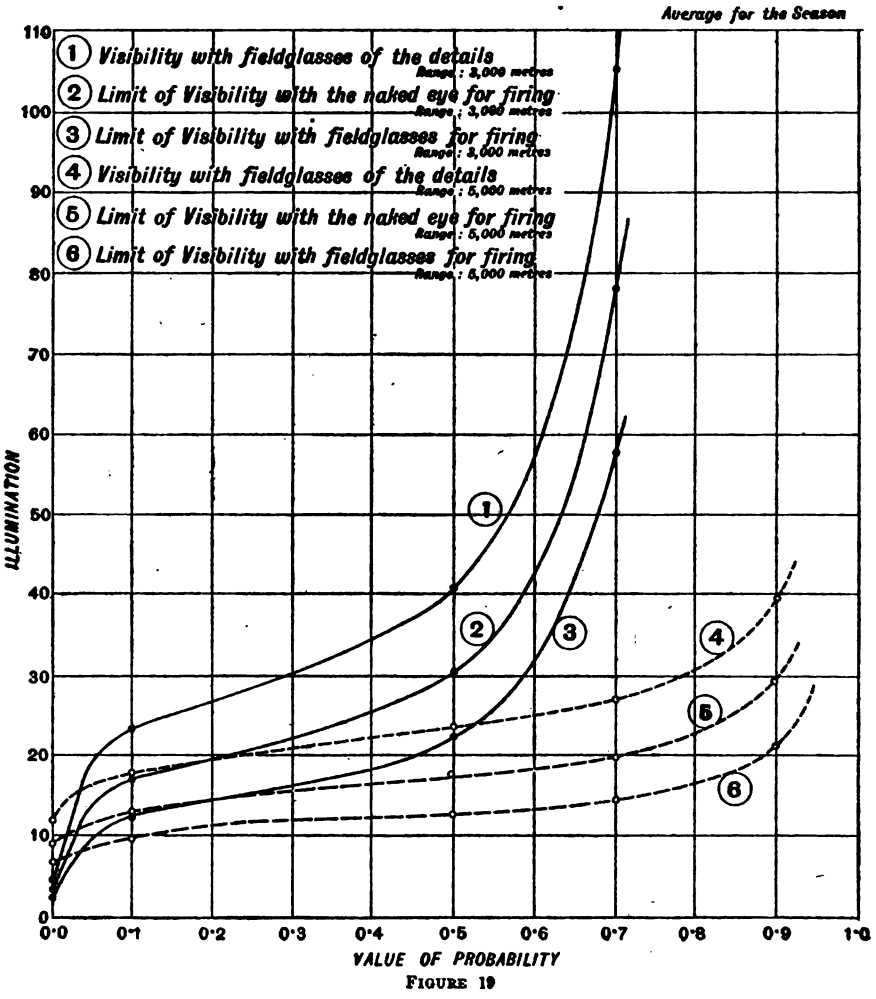


FIGURE 19

By comparing the curves in Fig. 19 for a range of 3,000 metres in the north and of 5,000 metres in the south a considerable difference will be noticed due to the atmospheric transparency. Thus, the visibility of details with field-glasses at a range of 5,000 metres and the probability value of 9/10, only requires an illumination of 39·05 lux, whereas in the north it is difficult to attain this high probability, and to do so would require a searchlight of abnormal size.

(6) *Visibility of a Detachment of Infantry in a Mountainous Climate,* $l' = l$.—We have assumed that it is desired to illuminate a detachment of infantry in a mountainous climate against a snowy background. The illumination equivalent to the limit of visibility with the naked eye is 1·5 lux. For a large mass of infantry this illumination falls to 1 lux.

The curve immediately indicates that if it is desired to see the detachment at a distance of 3,000 metres (assuming the searchlight and the observer to be at equal distances from the objective) an illumination of 15·95 lux will be required; and if the range is 5,000 metres 50·85 lux.

For a mass of infantry 10·64 lux would be sufficient at a distance of 3,000 metres and 33·9 lux at a distance of 5,000 metres.

In actual practice the visual sharpness or acuity would make it impossible to observe with the naked eye a small detachment of foot soldiers at a distance of 5,000 metres, and field-glasses would be required; probably, however, a large mass of infantry could be distinguished.

If these figures are compared with those previously given it will be seen what an enormous advantage is realised by the extreme transparency of the air in mountainous districts, and by the effect of contrast due to the snowy background.

MARINE OBJECTIVES.—(7) *Visibility of an Armoured Warship, $l' = l$.*—For the limit of visibility with glasses to permit of firing at a large armoured warship, the equivalent illumination is 0·23 lux.

We have traced in Fig. 20 curves corresponding to the limit of visibility with glasses for a range of 5,000 metres in two different climates—in the Channel and in the Mediterranean—for values of the transparency coefficient as an annual average. (See Table XII.)

From this, the conclusion is drawn that it would not be possible in the Channel to obtain the limit of visibility for a probability value of 9/10; whereas in the Mediterranean there will be no difficulty in attaining the necessary illumination of 19·15 lux.

(8) *Visibility of a Dark-coloured Torpedo-boat, $l' = l$.*—The equivalent illumination corresponding to the limit of visibility with glasses in the case of a dark-coloured torpedo-boat is 0·70 lux.

If a good visibility of the details with glasses is desired, 1 lux must be allowed for.

In Fig. 21 are shown the corresponding curves of illumination, where they are given for the two climates—the Channel (annual average) and the Mediterranean (annual average)—for a range of 3,500 metres. As in the case of the armoured warship, it will not be possible to attain, without the use of searchlights of abnormal size, a probability of more than 7/10 in the Channel; whereas in the Mediterranean, with normal sizes of searchlights, it will be easy to obtain a probability of 9/10. (See Table VI.)

(9) *Visibility of a Black Buoy or of the Turret of a Submarine, $l' = l$.*—The illumination of a buoy is referred to in Fig. 22, the equivalent illumination of which, for the limit

of visibility with glasses, is 4·8 lux. In the same figure is also indicated the illumination of the turret of a submarine,

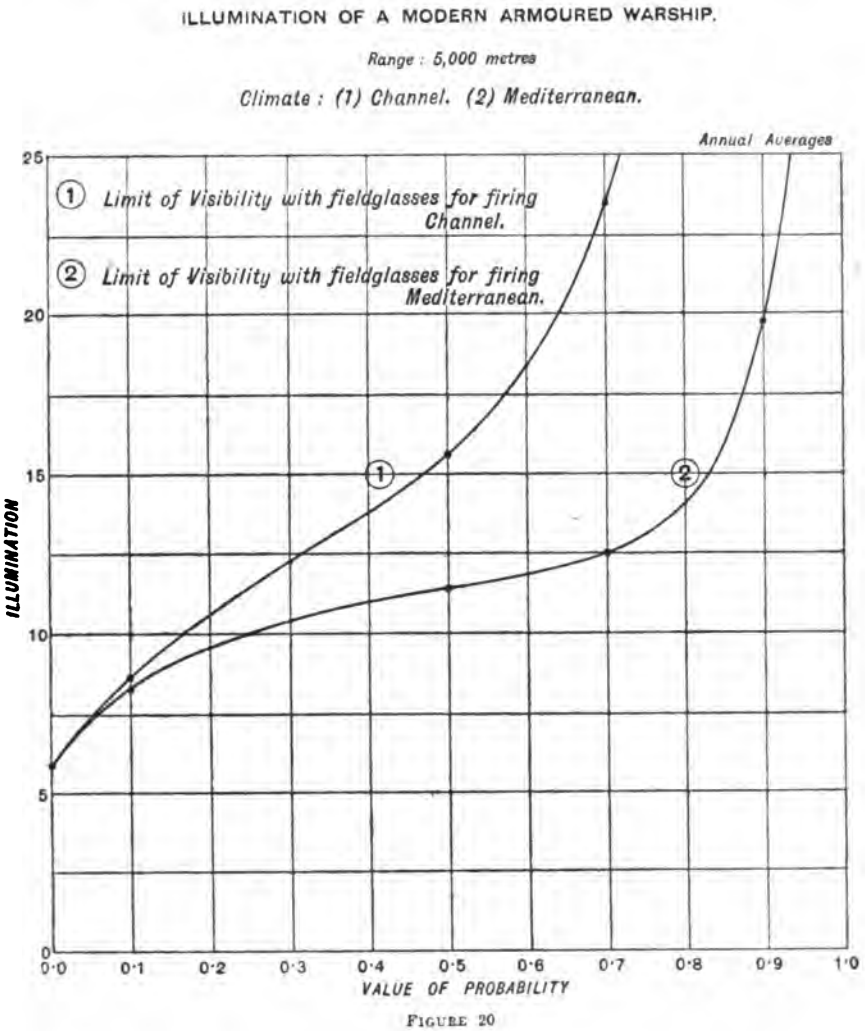


FIGURE 20

the equivalent illumination being 5 lux. The range of 1,800 metres has been assumed to be the same in the two cases. The illumination curves are for the annual average climates of the Channel and the Mediterranean.

ILLUMINATION OF A TORPEDO BOAT OF DARK COLOUR.

Range : 8,600 metres

Climate : (1) Channel; (2) Mediterranean.

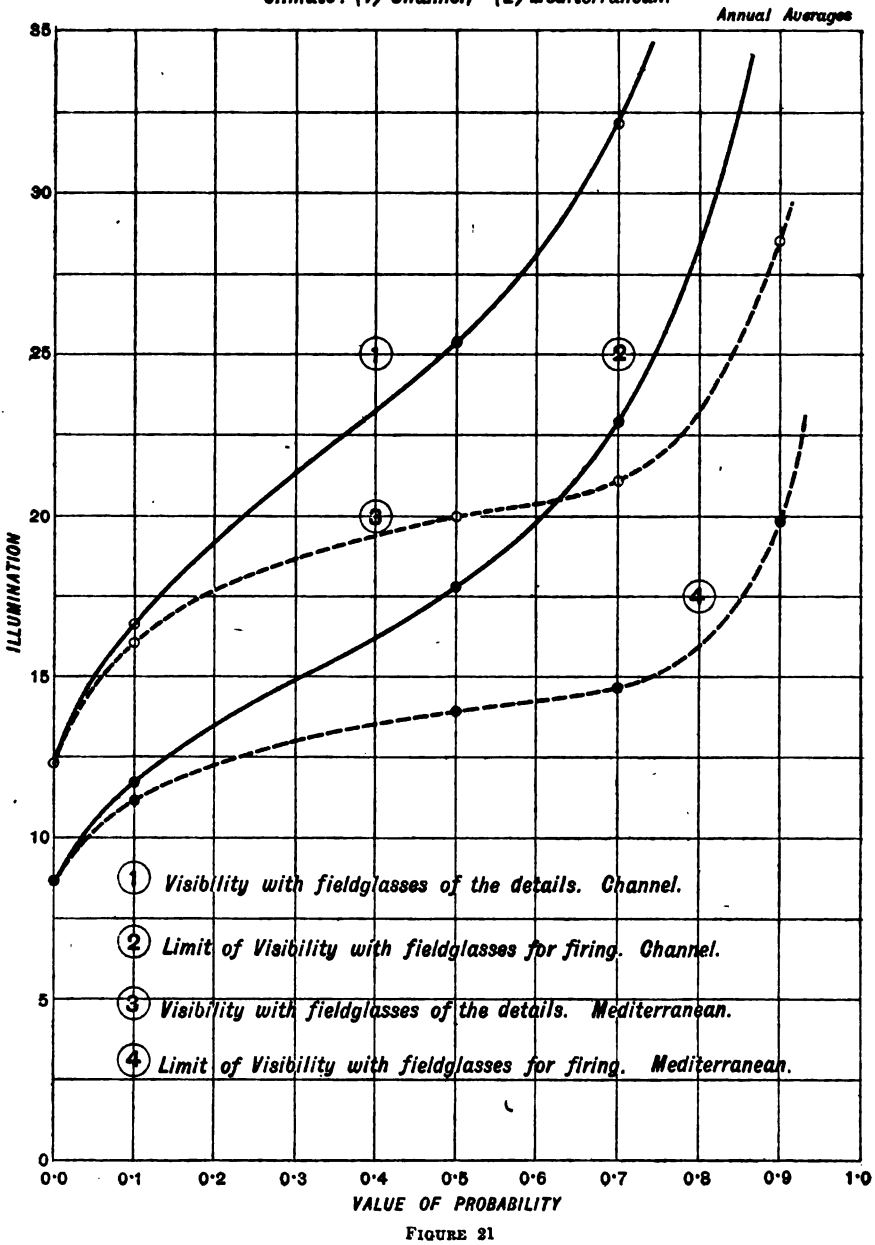


FIGURE 21

It will be seen that with the Channel climate, and in order to illuminate a black buoy and to attain a probability of 9/10, an illumination of 65·8 lux is necessary, and for the turret of a submarine 68·5 lux; whereas for the Mediterranean climate these values are reduced to 24·5 lux and 25·5 lux respectively.

If reference is made to the equivalent illuminations in Table XVI., it will be seen that the illumination of a red buoy is much more favourable. No calculations have been worked out with this hypothesis, but the curve will make it possible to readily obtain the necessary illuminations for any particular range and climate.

Problem of Illumination in which the Range is to be Determined, the Illumination of the Searchlight and the Nature of the Objective being already known.

This problem is the inverse of the preceding one. Assuming that a given size of searchlight is available and that the practical illumination is known, the question to be asked is, What will be the range which can be obtained under certain given atmospheric conditions for a given objective?

In the following examples it has been assumed that the observer and the searchlights were placed at equal distances from the objective, that is to say, $l' = l$.

Illumination of a Village, a Crossing of Roads, and a Bridge, with 0·60 metre and 0·90 metre Searchlights (Ranges Required).—It is assumed that the 0·60 metre searchlight has a focal length equal to 40 per cent. of the mirror diameter and that it is provided with high voltage carbons and flashing shutters.

Under these conditions it is found that $\epsilon_p = 16{\cdot}7$ lux.

ILLUMINATION OF A BLACK BUOY.

ILLUMINATION OF A SUBMARINE TURRET.

Range : 1,800 metres

Climate : (1) Channel; (2) Mediterranean

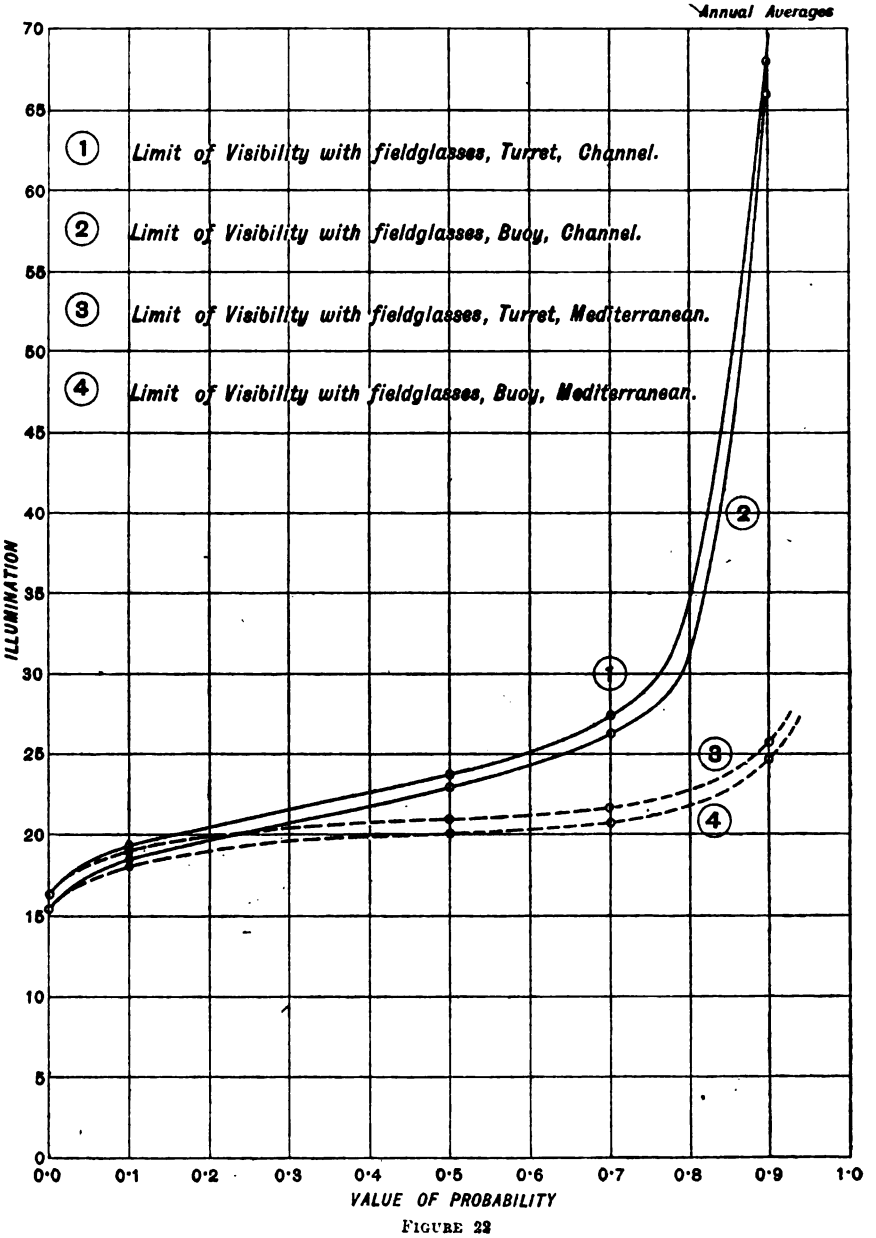


FIGURE 22

The 0·90 metre searchlight is also provided with high voltage carbons and flashing shutters, and has a focal

ILLUMINATION OF A VILLAGE, BRIDGE, OR A CROSSING OF ROADS.

Probable ranges for a Searchlight of 0·60 metre and for a Searchlight of 0·90 metre for the limit of visibility with fieldglasses for firing.

Climate: East of France (in Summer)

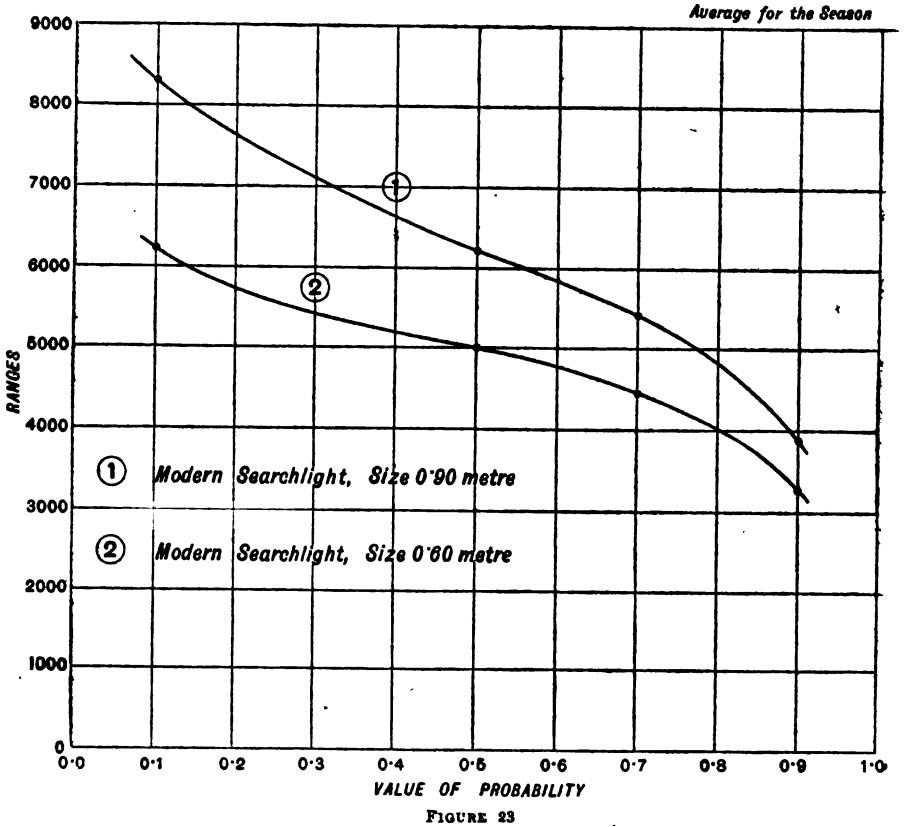


FIGURE 23

length equal to 40 per cent. of the mirror diameter. Table VI. indicates that the practical illumination ϵ_p is equal to 33·56 lux.

The equivalent illumination ϵ_e of the objective in question is 0·27 lux, being the limit of visibility with glasses.

We finally assume that the climate chosen is summer in the East of France, for instance in Champagne. (See Table XIII.)

ILLUMINATION OF A BODY OF INFANTRY IN DARK UNIFORMS.

Probable range for a Searchlight of 0·90 metre and for a Searchlight of 0·60 metre for the limit of visibility with fieldglasses.

Climate : East of France (In Spring)

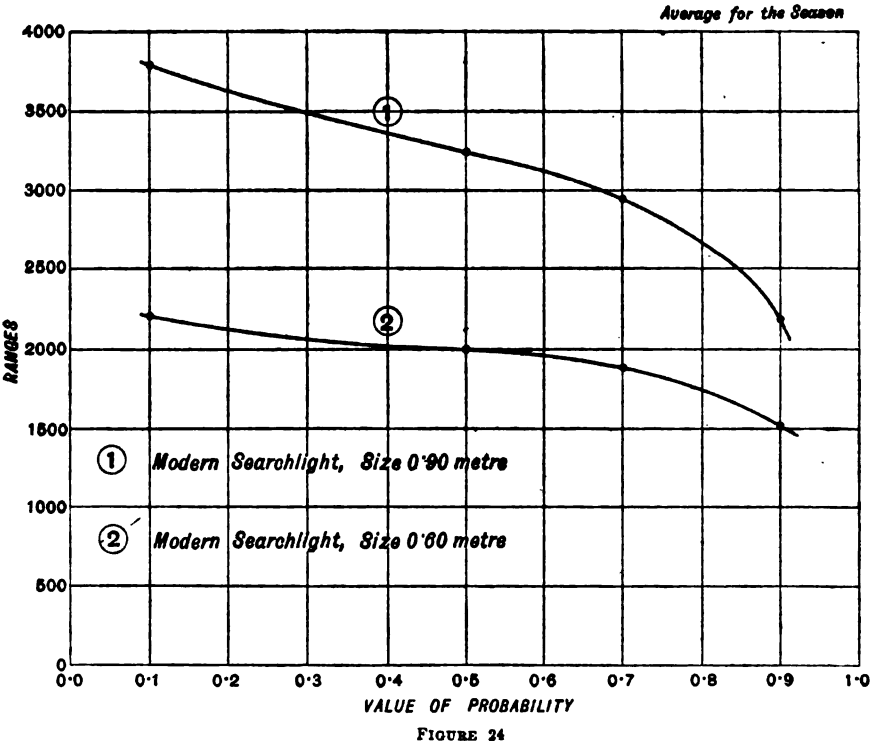


FIGURE 24

The preceding curves and tables make it possible to calculate the ranges which will be obtained. The curves in Fig. 23, which summarise these calculations, have as abscissæ the value of the probability and as ordinates the ranges.

It will be seen that the 0·60 metre searchlight will have a range of 6,250 metres in the most favourable case,

with a probability of 1/10. At the probability value of 9/10 the range will fall to 3,300 metres.

For the 0·90 metre searchlight the ranges will be respectively 8,300 and 3,920 metres.

ILLUMINATION OF A TROOP OF INFANTRY IN DARK UNIFORMS (RANGES REQUIRED).—The same searchlight is employed as before.

The equivalent illumination of the objective $\epsilon_0 = 1{\cdot}8$ lux as representing the limit of visibility with glasses for firing. The climate assumed is that of spring in the East of France, Argonne for instance. (See Table XIII.)

In the most favourable case, the 0·90 metre searchlight will give a range of 3,800 metres, and that of the 0·60 metre searchlight a range of 2,200 metres.

For a probability value of 9/10 these ranges will be reduced to 2,225 and 1,510 metres respectively.

ILLUMINATION OF A FORT, A PERMANENT STRUCTURE, OR A CHURCH STEEPLE (RANGES REQUIRED).—These two illuminations correspond to the same equivalent illumination $\epsilon_0 = 0{\cdot}23$ lux, for the limit of visibility, either with glasses for the fort or with the naked eye for the steeple.

With the same sizes of searchlights as those considered above, *i.e.*, 0·60 metre and 0·90 metre, and a climate assumed to be in the North of France and Belgium in winter (see Table XIV.), an enormous variation of the range for the probability values of 1/10 and 9/10 will be seen. In this connection the curves in Fig. 25 are very instructive.

ILLUMINATION OF A MODERN ARMOURED WARSHIP (RANGES REQUIRED).—The curves in Fig. 26 compare the illumination of an armoured warship by two searchlights,

one having a diameter of 1·50 metres and the other of 2 metres, the largest at present in use on the coasts.

ILLUMINATION OF A FORT, A PERMANENT BATTERY, OR OF A STEEPLE.

Probable ranges of a Searchlight of 0·90 metre and of a Searchlight of 0·60 metre
Limit of visibility with fieldglasses for the Fort.
Limit of visibility with the naked eye for the Steeple.

Climate: North of France and Belgium (in Winter).

Average for the Season

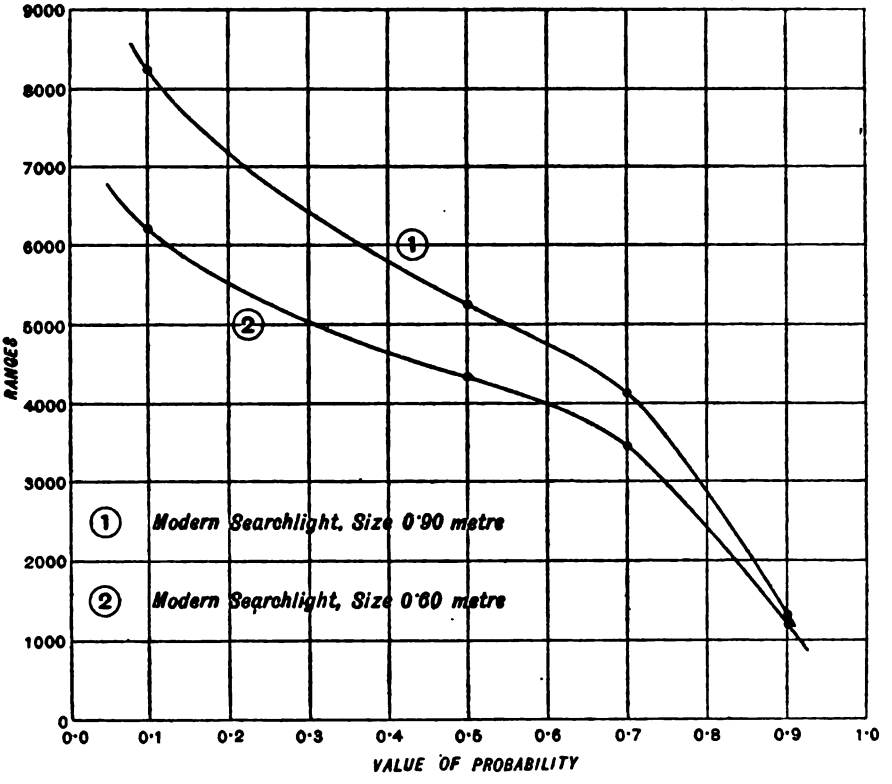


FIGURE 25

The assumed climate is that of the Channel at its annual average. (See Table XXII.)

The limit of visibility with glasses corresponds to an illumination of 0·23 lux.

With a focal length of 60 per cent. of the mirror diameter, high voltage carbons, and flashing shutters, the practical illumination ϵ_p of these searchlights is 96·8 lux for the

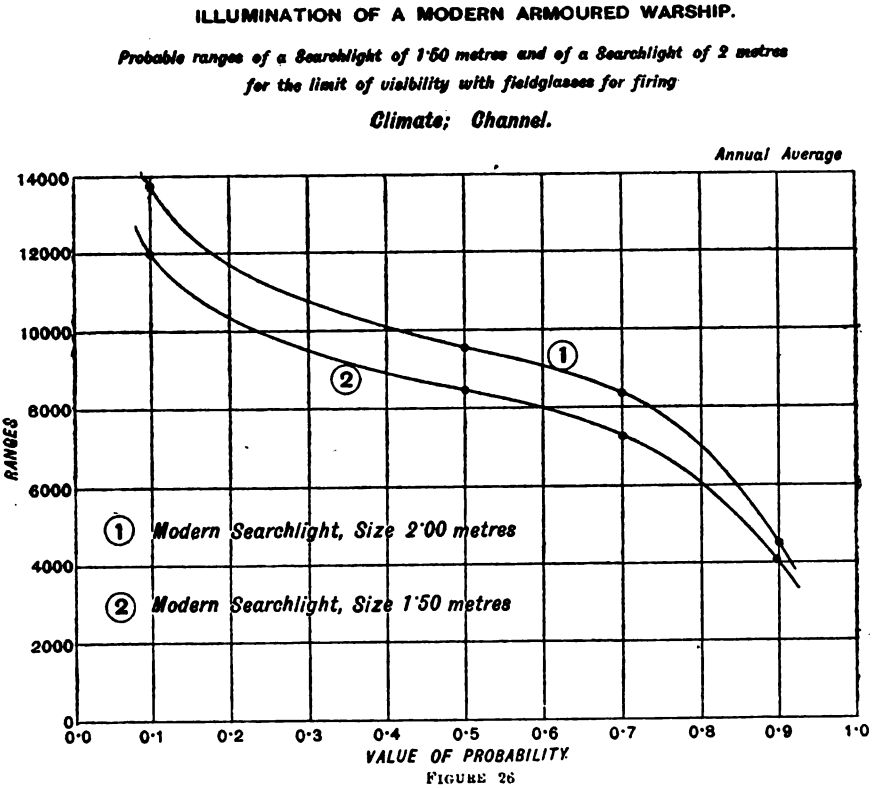


FIGURE 26

1·50 metre searchlight and 164·8 lux for the 2 metre searchlight. (See Table VI.)

It is interesting to note that, according to Fig. 26, the range would reach 13,800 metres for the 2 metre searchlight and 12,000 metres for the 1·50 metre searchlight for a probability of 1/10, but that it would fall to 4,490 and 4,100 metres respectively for the probability value of 9/10. It

must, however, be noted that the extreme figures given for the ranges must only be accepted as approximate, because the phenomenon of the visual sharpness interferes with the

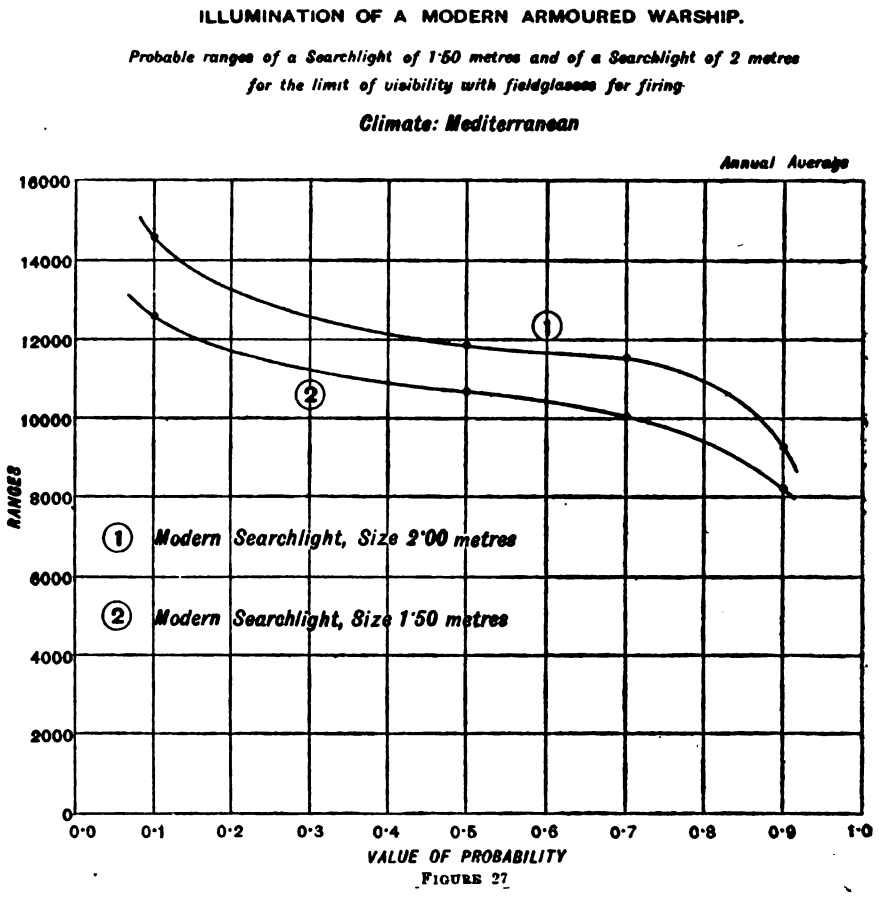


FIGURE 27

visibility at a great distance and always tends to reduce the range.

In Fig. 27 are shown the curves corresponding to the same objectives for the annual average climate of the Mediterranean (see Table XII.), the two searchlights compared remaining the same.

ILLUMINATION OF A DARK-COLOURED TORPEDO-BOAT (RANGES REQUIRED).—In Fig. 28 are shown the compared ranges of two searchlights, one of 0·90 metre, the other of 1·10 metres diameter, of modern construction, with high

ILLUMINATION OF A TORPEDO BOAT OF DARK COLOUR.

Probable ranges of a Searchlight of 0·90 metre and of a Searchlight of 1·10 metres for the limit of visibility with fieldglasses for firing

Climate: Channel.

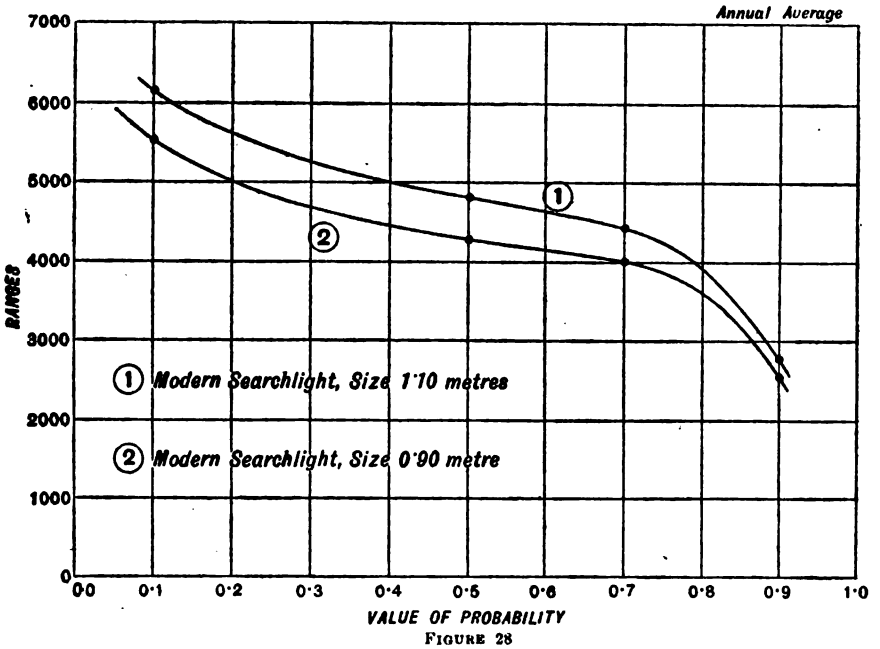


FIGURE 28

voltage carbons, flashing shutters, and a focal length of 40 per cent. of the mirror diameter.

The limit of visibility with glasses for the objective in question corresponds to $\epsilon_o = 0{\cdot}7$ lux.

The climate chosen in Fig. 28 is that of the Channel (annual average).

In Fig. 29 the ranges are given, the same objective and

searchlights, corresponding to the climate of the Mediterranean.

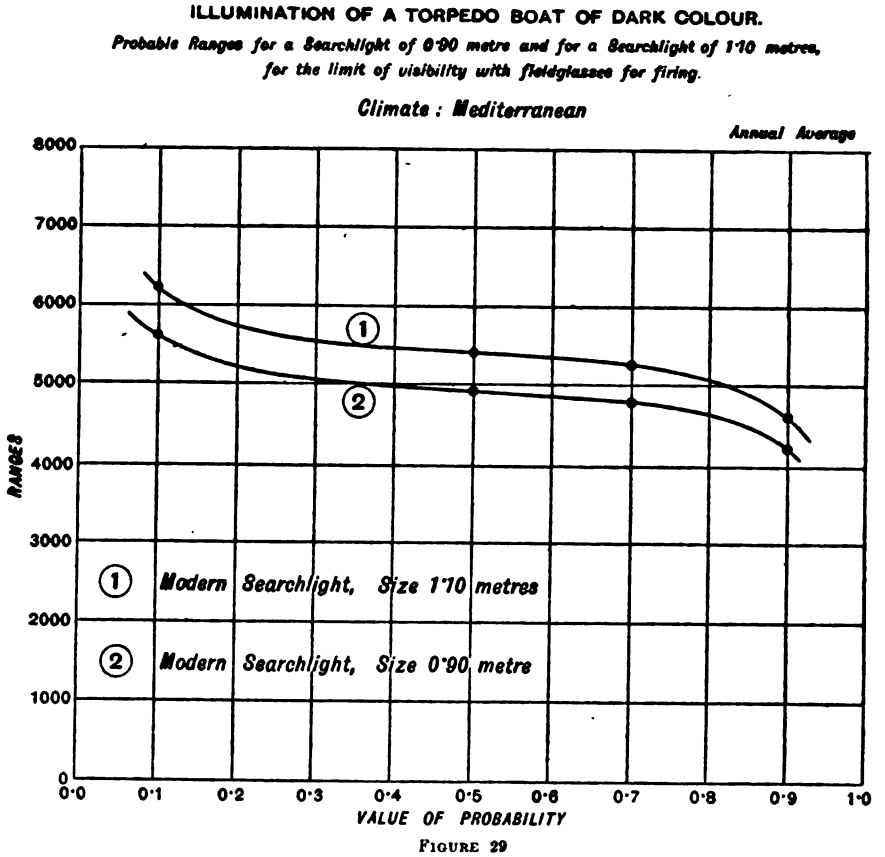


FIGURE 29

DETERMINATION OF THE RANGES, THE DISTANCES FROM THE OBJECTIVE TO THE SEARCHLIGHT AND TO THE OBSERVER BEING DIFFERENT.

As previously explained, the general curves in Fig. 10 make it possible to solve the general problem of ranges, where the distance l between the searchlight and the objective and the distance l' between the observer and the objective are no longer the same.

In order to illustrate the manner of applying the curves we shall examine two cases—one referring to a military operation on a land objective and the other to an operation on a marine objective.

ILLUMINATION OF A TRENCH.—In Table XVI. are given the equivalent illuminations ϵ_o for a series of objectives, but corresponding values are not given for modern campaign trenches and works.

Experiments in respect of the illumination of modern trench works are not very numerous, but the two following approximate values will be of interest :—

Limit of visibility with glasses, $\epsilon_o = 0{\cdot}35$ lux.

Good visibility with glasses, $\epsilon_o = 0{\cdot}5$ lux.

Taking this latter value of the equivalent illumination, assume that it is desired to illuminate a trench with the aid of a 0·90 metre searchlight having a focal length of 40 per cent. and provided with high voltage carbons and flashing shutters.

Table VI. shows the practical illumination in such a case to be $\epsilon_p = 33{\cdot}56$ lux.

The illuminated field under these conditions is given in Table IV., and corresponds to an illuminated zone 50 metres in diameter at a distance of 1,000 metres.

The general curves of Fig. 10 comprise in double series the scale which corresponds to the ratio $\frac{\epsilon_o}{\epsilon_p}$, as does also the scale which corresponds to the coefficients of transparency.

In order to facilitate the readings we have in effect multiplied the normal scale by a coefficient, which makes it possible to give to the double scale a far greater extension. Thus the normal scale of the transparency coefficient is from the value 1 to 0·10. The second scale is from the value 1 to 0·80.

Regarding the scale $\frac{\epsilon_o}{\epsilon_p}$, this is also largely extended, and the scale comprises the space between 0·000001 and 0·02.

Under these conditions it is easy to calculate the values l and l' corresponding to the example under consideration of the illumination of a trench.

In Table XVII. are given the values of $\frac{l'}{l}$, read on the curves and corresponding to a value of the transparency coefficient of $a = 0{\cdot}911$, that is, to the average weather of climate No. 2, or a probability value of 5/10.

Upon examination of the values in Table XVII. it will immediately be seen that, if the observer is indefinitely brought nearer to the object when the distance l' is equal to zero, the range of the searchlight, *i.e.*, the distance which separates it from the object, attains the extreme value of 6,150 metres.

On the contrary, if the observer goes further away from the object, the value l' increases and the value l diminishes in proportion.

We have continued the calculation until the value of the ratio $\frac{l'}{l} = 2$, which means that

$$l = 4{,}400$$
$$l' = 8{,}800$$

When the two values are equal,

$$l = l' = 5{,}080 \text{ metres.}$$

A special diagram is given in Fig. 30 which summarises these calculations. It has been drawn in polar form, starting from a circle the diameter of which is equal to the value of l, when $l' = 0$. A vector which starts from the origin gives

by its intersection with this circle the distance l; the distance l' is represented by that part of the vector between the circle and the curve which limits the sum of the two distances $l + l'$. As the curve in Fig. 10 does not allow the

TABLE XVII.—ILLUMINATION OF A TRENCH.

Equivalent illumination. . $\epsilon_o =$ 0·5 lux.
Practical illumination . . $\epsilon_p =$ 88·56 lux (0·90 metre searchlight).
Coefficient of transparency . . $a =$ 0·911 lux.
Value of the ratio . . . $\frac{\epsilon_o}{\epsilon_p} =$ 0·0149 lux.

Ratio $\frac{l'}{l}$.	Distance of the Searchlight to the Objective l.	Distance of the Observer to the Objective l'.
$\frac{l'}{l} = 0$	$l =$ 6,150 metres	$l' =$ 0 metre
$\frac{l'}{l} = 0{\cdot}25$	$l =$ 5,800 ,,	$l' =$ 1,500 metres
$\frac{l'}{l} = 0{\cdot}50$	$l =$ 5,500 ,,	$l' =$ 2,750 ,,
$\frac{l'}{l} = 0{\cdot}75$	$l =$ 5,300 ,,	$l' =$ 3,975 ,,
$\frac{l'}{l} = 1{\cdot}00$	$l =$ 5,080 ,,	$l' =$ 5,080 ,,
$\frac{l'}{l} = 1{\cdot}50$	$l =$ 4,700 ,,	$l' =$ 7,050 ,,
$\frac{l'}{l} = 1{\cdot}75$	$l =$ 4,550 ,,	$l' =$ 7,960 ,,
$\frac{l'}{l} = 2{\cdot}00$	$l =$ 4,400 ,,	$l' =$ 8,800 ,,

ratio $\frac{l'}{l} = 2$ to be exceeded, the tracing of Fig. 30 has been completed by a calculation with the aid of the general formula (26), from which is obtained

$$l + l' = \frac{\log\left(\frac{\epsilon_o}{\epsilon_p}\right) + 2\log(l)}{\log a} \qquad (28)$$

It is easy to see that as the distance between the searchlight and the object decreases, the distance between the observer and the object rapidly increases.

From a practical point of view in the use of searchlights, these considerations will be of considerable importance.

Suppose that it is desired to carry out a night operation on enemy trenches, under the atmospheric conditions assumed in the calculation, an attempt will first of all be made to place the searchlight as far as possible from the object to be illuminated in order to diminish the probability of its being hit by the artillery firing. For instance, in the case under consideration, the 0·90 metre searchlight would be placed at a distance of 5,000 metres from the object. At that distance a sufficient visibility would be obtained, and the diagram shows that the observer might be placed at practically the same distance.

If the position of the searchlight appears dangerous and it is desired to take it still further away, it will then be necessary to bring the observer nearer the objective in order to maintain the same visibility.

The diagram indicates that if the searchlight were to be withdrawn to a distance of 5,800 metres from the object, it would be sufficient if the observer were to approach to a distance of 1,650 metres in order to see distinctly the objective to be attained. Under such conditions, it would naturally be necessary to connect the observer and the searchlight by a telephone, so as to enable the former to give the necessary directions to those in charge of the working of the searchlight.

The opposite case might also present itself. It might be found possible to take the searchlight nearer the object and to place the observer further away; for instance, if for various reasons the batteries under orders to attack the enemy were to be placed at a great distance. Thus, the

calculation shows and the drawing indicates that if the searchlight is placed at a point 4,700 metres from the objective, the observer may safely install himself at a distance of 7,050 metres and give, from there, his instructions to the batteries attacking at that distance.

Calculations have been made respecting the increase of the values of the ratio $\frac{l'}{l}$ until $l = 1$ kilometre and $l' = 44$ kilometres. Theoretically it is possible to conceive that the searchlight comes ever nearer to the objective until it actually coincides with it. The observer then withdraws to a maximum distance, which is easily obtained by calculation. In view of this, it is sufficient to note that an object placed at the distance of 1 metre from the searchlight receives the maximum illumination obtainable from the searchlight and that the distance l', at which the observer finds himself, is naturally a maximum. If it is desired to calculate this extreme case, the values l and l' must be given in metres instead of kilometres, and the coefficient will also correspond to a length of 1 metre instead of 1 kilometre.

Thus for the objective under consideration,

$$l = 1 \text{ metre}, \quad l' = 265{\cdot}50 \text{ kilometres}.$$

These calculations only present a theoretical interest to show the extreme limits of the law of ranges. It must, however, never be lost sight of that the visual sharpness restricts the visibility at a great distance and leads to quite different numerical values, which, in the present state of knowledge on the technics of searchlights, we are unfortunately not yet able to calculate.

ATTACK ON A COAST FORTRESS BY A SQUADRON.—This

second example is of great interest, because it refers to a case which may easily occur in practice.

If it is supposed that a coast fortress is attacked by a squadron, the assailing warships will naturally range themselves at the greatest possible distance in order to diminish the effectiveness of the enemy's firing. It will be entirely to their advantage during the night to have their lights screened and not make use of their searchlights, or at least as little as possible. It will nearly always be desirable to entrust the illumination to light vessels, cruisers, and others which are able to manœuvre quickly to any position.

Under these conditions, the distance l between the searchlight and the objective will generally be less than the distance l' between the observer and the objective, seeing that the observer will naturally be placed on the assailing armoured warships.

Table XVI. gives the equivalent illuminations, and also indicates the value $\epsilon_o = 0{\cdot}45$ lux, which represents a good visibility with glasses, of a fort.

We assume that the available searchlight has a diameter of 1·10 metres with high voltage carbons and flashing shutters, the focal length being 60 per cent. of the mirror diameter.

Table VI. then gives $\epsilon_p = 57{\cdot}05$ lux for the value of the equivalent illumination.

We also assume that the operation takes place in the Mediterranean during average weather, corresponding to $a = 0{\cdot}932$. (See Table XII.)

In Table XVIII. and in Fig. 31, which is really the same as the former, are shown the results given by the general curve.

It will be seen that it is possible for the distance l, which is the limit between the searchlight and the objective, to attain 8,350 metres when

$$l' = 0$$

When the ratio $\frac{l'}{l} = 1$, $l = l' = 6{,}900$ metres.

If the look-out ship operating the searchlights approaches to within 2,000 metres of the fortress, the assailing ship can place itself at a distance of 8,000 metres.

TABLE XVIII.—ILLUMINATION OF A COAST FORTRESS.

Equivalent illumination . . $\epsilon_o =$ 0·45 lux.
Practical illumination . . $\epsilon_p =$ 57·05 lux (1·10 metre searchlight).
Coefficient of transparency . $a =$ 0·932 lux.
Value of the ratio . . . $\frac{\epsilon_o}{\epsilon_p} =$ 0·00789 lux.

Ratio $\frac{l'}{l}$.	Distance of the Searchlight to the Objective l.	Distance of the Observer to the Objective l'.
$\frac{l'}{l} = 0$	$l = 8{,}350$ metres	$l' = 0$ metre
$\frac{l'}{l} = 0{\cdot}25$	$l = 8{,}000$ „	$l' = 2{,}000$ metres
$\frac{l'}{l} = 0{\cdot}50$	$l = 7{,}500$ „	$l' = 3{,}750$ „
$\frac{l'}{l} = 0{\cdot}75$	$l = 7{,}250$ „	$l' = 5{,}440$ „
$\frac{l'}{l} = 1{\cdot}00$	$l = 6{,}900$ „	$l' = 6{,}900$ „
$\frac{l'}{l} = 1{\cdot}50$	$l = 6{,}400$ „	$l' = 9{,}600$ „
$\frac{l'}{l} = 1{\cdot}75$	$l = 6{,}200$ „	$l' = 10{,}900$ „
$\frac{l'}{l} = 2{\cdot}00$	$l = 6{,}000$ „	$l' = 12{,}000$ „

When the ratio $\frac{l'}{l}$ increases and attains the value 2, the look-out ship being placed at $l = 6{,}000$ metres, the assailant can withdraw to 6,000 metres.

The example demonstrates the practical use of the general curve and its uses for the most varied problems that are required to be solved.

For the extreme values,

$$l = 1 \text{ metre}, \; l' = 193{\cdot}50 \text{ kilometres},$$

the calculation is the same as in the preceding example, but special reservations must be made in respect of the influence of visual sharpness.

CHAPTER IX

THE VARIATION IN THE RANGES ACCORDING TO THE SIZE OF SEARCHLIGHT AND THE ATMOSPHERIC TRANSPARENCY

In a preceding chapter we have analysed the variation in the practical illumination given by a series of searchlights, depending upon the diameter of the reflector.

In Figs. 5 and 6 are given curves of the practical illumination ϵ_p as a function of the size of searchlight. Effort has been made to find the equation of these curves, which are exponentials, the exponent being a constant.

A similar investigation may be carried out in respect of the ranges. In effect, the question may be asked how the ranges vary with the diameter of the searchlight.

If a series of searchlights are taken having the same ratio of focal length to the diameter, it is possible to calculate the various ranges obtainable for a given coefficient of atmospheric transparency and a specified objective.

In Fig. 6 is given the curve of ranges for a series of searchlights, the focal length of which is 60 per cent. of the diameter, assuming an objective with an equivalent illumination of $\epsilon_o = 0{\cdot}5$ lux, an atmospheric transparency with a coefficient $a = 0{\cdot}90$ and an equality of the distances l and l'.

It will be observed that the curve in question is concave in respect to the abscissa, or the diameters of the searchlights. On the other hand, the curve of the illumination is convex in respect to the abscissa.

The analytical examination of the curve of the ranges in Fig. 6 shows that it is an exponential, the equation of which is as follows :

$$l = (2\Delta)^{0{\cdot}575} \tag{29}$$

l being given in kilometres, and Δ, diameter of the mirror, in decimetres.

If the equation (29) is compared to the formula (20), which refers to the curve of illumination, it will immediately be seen that the exponent of the exponential of the ranges 0·575, is much lower than the exponent of the exponential of the illumination. The range therefore increases far more slowly than the illumination for the same series of searchlights.

It may now be asked whether the formula, which connects the range to the diameter of the reflector, varies considerably with the coefficient of transparency.

In order to study the question, the ranges have been calculated for a series of searchlights having a focal length of 60 per cent. of the diameter and for a series of values of the transparency coefficient, the three most important values being shown in Table XIX. Climate No. 1, North of France, is assumed, and the following three values of the annual average :—

Clear weather	$a = 0{\cdot}962$
Average weather	$a = 0{\cdot}900$
Misty weather	$a = 0{\cdot}644$

In Fig. 32 are shown the various curves of range, each corresponding to the preceding values of the transparency coefficient, and, for the sake of greater completeness, calculations have been made of the ranges corresponding to the intermediate values $a = 0{\cdot}70$, $a = 0{\cdot}80$, and, finally, to the value $a = 1$, where the transparency is perfect.

It will be seen that these various curves are really exponentials, as already indicated by the curve in Fig. 6.

These exponentials comprise, as being variable, the diameter of the reflector, or rather double of the diameter.

CURVES OF THE RANGES OF A SERIES OF SEARCHLIGHTS FOR DIFFERENT COEFFICIENTS OF TRANSPARENCY.

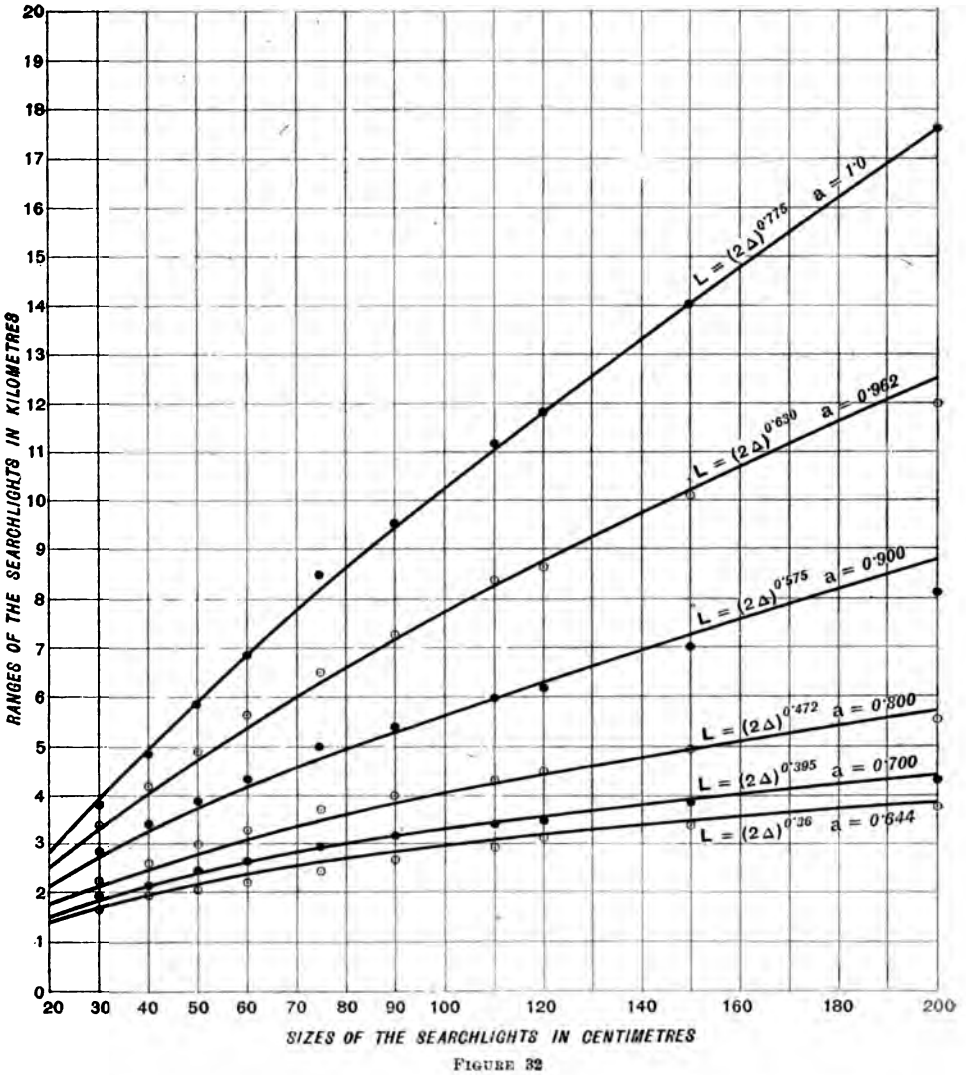


FIGURE 32

The exponent varies with the coefficient of transparency ; it reduces more than in proportion as the coefficient of transparency is reduced.

Thus, for the value $a = 0{\cdot}644$, the value of the exponent is 0·36.

For $a = 0{\cdot}8$, the exponent is 0·472.
For $a = 0{\cdot}962$, the exponent is 0·680.
Finally, for $a = 1$, the exponent is 0·775.

It will be seen that, even when the transparency is

TABLE XIX.—VARIATION OF THE RANGE WITH THE SEARCHLIGHT DIAMETER.

High voltage without flashing shutters, $\Delta = 1{\cdot}666\ f$ (Table VI.). $\epsilon_0 = 0{\cdot}5$ lux.

Diameter of the Reflector Δ.	Practical Illumination ϵ_p in lux.	Ratio $\frac{\epsilon_0}{\epsilon_P}$.	Ranges in Metres. (Annual Average. Climate North of France.)		
			Misty Weather $a = 0{\cdot}644$.	Average Weather $a = 0{\cdot}900$.	Clear Weather $a = 0{\cdot}962$.
Metres.			Metres.	Metres.	Metres
0·30	7·15	0·0695	1,770	2,830	3,350
0·40	11·97	0·0418	2,025	3,430	4,210
0·50	17·87	0·0288	2,230	3,900	4,960
0·60	24·60	0·02032	2,440	4,440	5,700
0·75	35·90	0·01392	2,670	5,000	6,500
0·90	46·75	0·01070	2,830	5,400	7,300
1·10	63·70	0·00785	3,020	6,000	8,350
1·20	71·00	0·00704	3,100	6,200	8,620
1·50	110·00	0·00454	3,390	7,000	10,010
2·00	181·50	0·00275	3,720	8,050	12,000

perfect, the increase in the range is smaller than the increase in the size of the reflector.

The mistakes made by taking the exponential curves just indicated instead of the actual points which would be given by the formula of ranges are very slight; they hardly attain 1 to 2 per cent. so long as the coefficient of transparency is not less than the value $a = 0{\cdot}6$.

All the foregoing calculations have been carried out on the assumption that the searchlight and the observer are at equal distances from the objective, that is, $l' = l$.

If the preceding considerations are summarised, it

may be said that the illumination varies as a power of the projector size approaching 2, and which, according to what has been observed, is approximately 1·72. The range varies with a power of the size, which approximately increases from 0·36 to 0·775 for coefficients of transparency, which also vary from 0·664 to unity.

These curves and their expressions in equations prove how enormous is the influence of the atmospheric transparency on the range.

If, therefore, it were desired to obtain ranges much greater than those obtained at present, it would be necessary to have searchlights of abnormal diameters, which would be quite immobile and unable to follow armies on active service or for warlike operations on land.

For ship work it is less difficult to utilise large sizes, because it is possible to arrange, during the construction of the ship and in advance, the position which they would occupy.

CHAPTER X

VISUAL ACUITY OR SHARPNESS

As explained in Part II. of this work, the phenomenon of visual sharpness always influences the visibility of the objects illuminated by electric searchlights.

This influence increases considerably as the size of the objects, or the visual angle subtended by them, diminishes. Where this angle falls below a certain limit the visibility only becomes possible by means of an enormous increase in the illumination.

Physiologists are in the habit of defining the visual sharpness as the angle subtended by the illuminated object. The unit of visual sharpness corresponds to an angle subtended by an object, the height of which is 5 minutes and a width of 1 minute. This is an extreme limit, which is usually not attained by an average sight. An eye, the visual sharpness of which is the unit, therefore corresponds to a piercing sight. Below this angle, in order to perceive the size and shape of an object, a quite exceptional sight is required.

The influence of the visual sharpness on the range of electric searchlights has been fully explained, from a theoretical point of view, by M. Blondel. In a note submitted to the Academy of Sciences on January 4th, 1915, and published in the issue of the "Comptes Rendus" of January 11th, M. Blondel gave the general formula of ranges, taking into account the visual sharpness, either for observation with the naked eye or for observation with the aid of glasses, the optical constants of which naturally enter into the calculation.

The general formulæ arrived at by M. Blondel, and which give the complete solution of the range problem, comprise several coefficients, and their determination essentially depends on the objectives under consideration. The colour of the objects and that of the background, the dimensions and the shape of the illuminated objects, the contrast between the object and the background, are elements which all act on the visual sharpness and which render the study of the coefficients particularly difficult.

In a second note, which appeared in the issue of the "Comptes Rendus" of January 25th, 1915, M. Blondel has attempted to determine the order of magnitude of one of the most important constants of these formulæ, and in order to demonstrate the effect of the visual sharpness he has applied it to the calculation of the illumination of a specified object.

In this way M. Blondel has been able to demonstrate that for a specified object, the height of which for instance is 1·75 metres, and which is visible under a known illumination at a distance of 1,000 metres, is transferred to a distance of 5 kilometres, the influence of the visual sharpness alone would require an increase in the illumination considerably more than that which would be required by an increase in the distance and the atmospheric absorption.

It is therefore certain that for objects of small dimensions the influence of the visual sharpness becomes preponderant, where it is desired to greatly increase a range obtained with a specified size of searchlight.

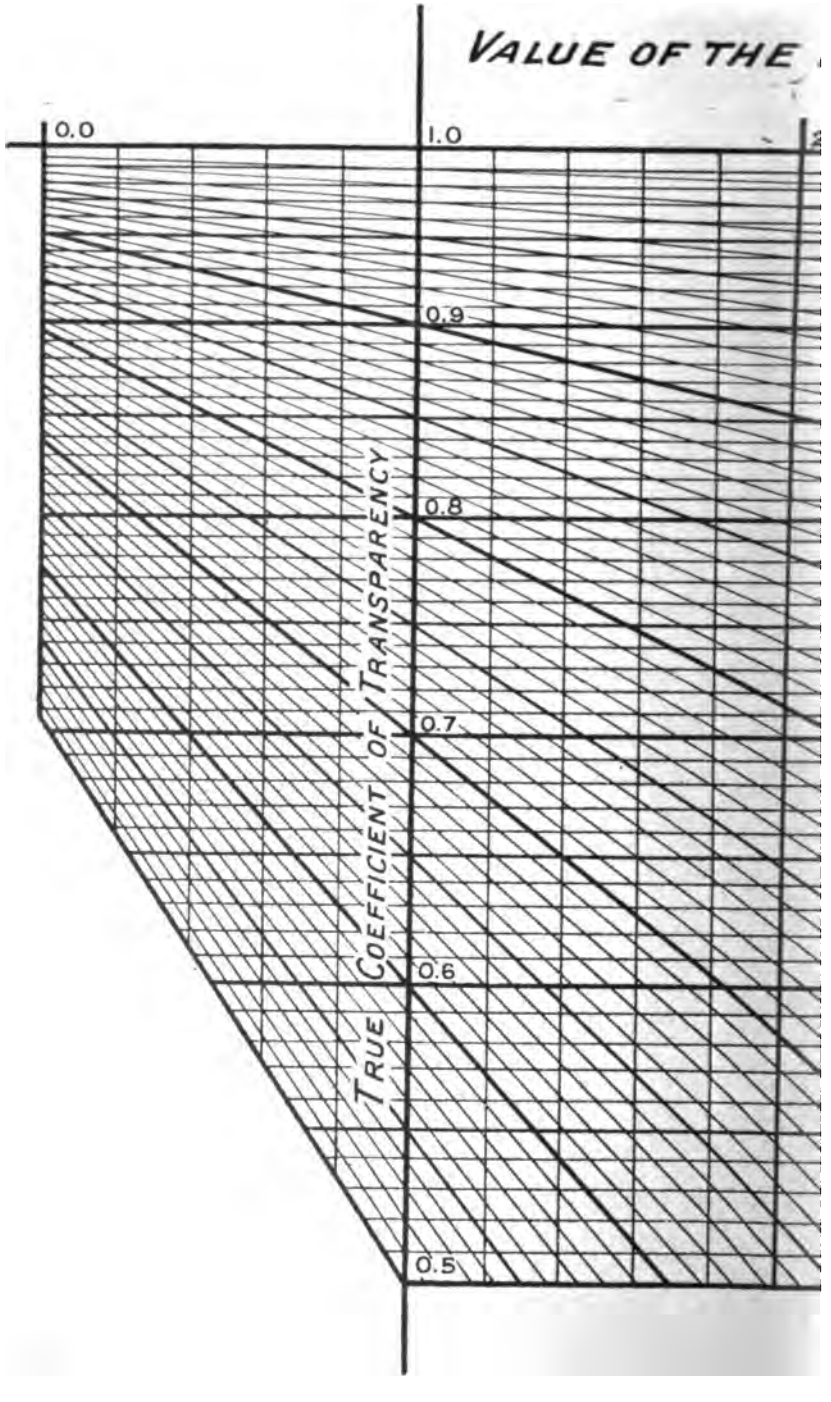
Unfortunately, in order to use in practice the new formulæ by M. Blondel it would be necessary for each objective, to carry out a series of experiments at variable ranges and well-defined illuminations, as well as determining in advance the coefficient of transparency. Only in this way would

it be possible to fix the values of the coefficients which enter into the complete formulæ.

In none of the experiments referred to which were carried out by the military commissions, either in France or abroad, have methodical observations been obtained capable of determining the coefficients of visual sharpness. However, these experiments have made it possible to approximately fix the equivalent illumination. The value of the equivalent illumination itself already takes into account the influence of visual sharpness, but in an incomplete manner, which makes it impossible to deduce therefrom the exact values of the ranges, when departing to any great extent from the conditions under which the experiments were carried out.

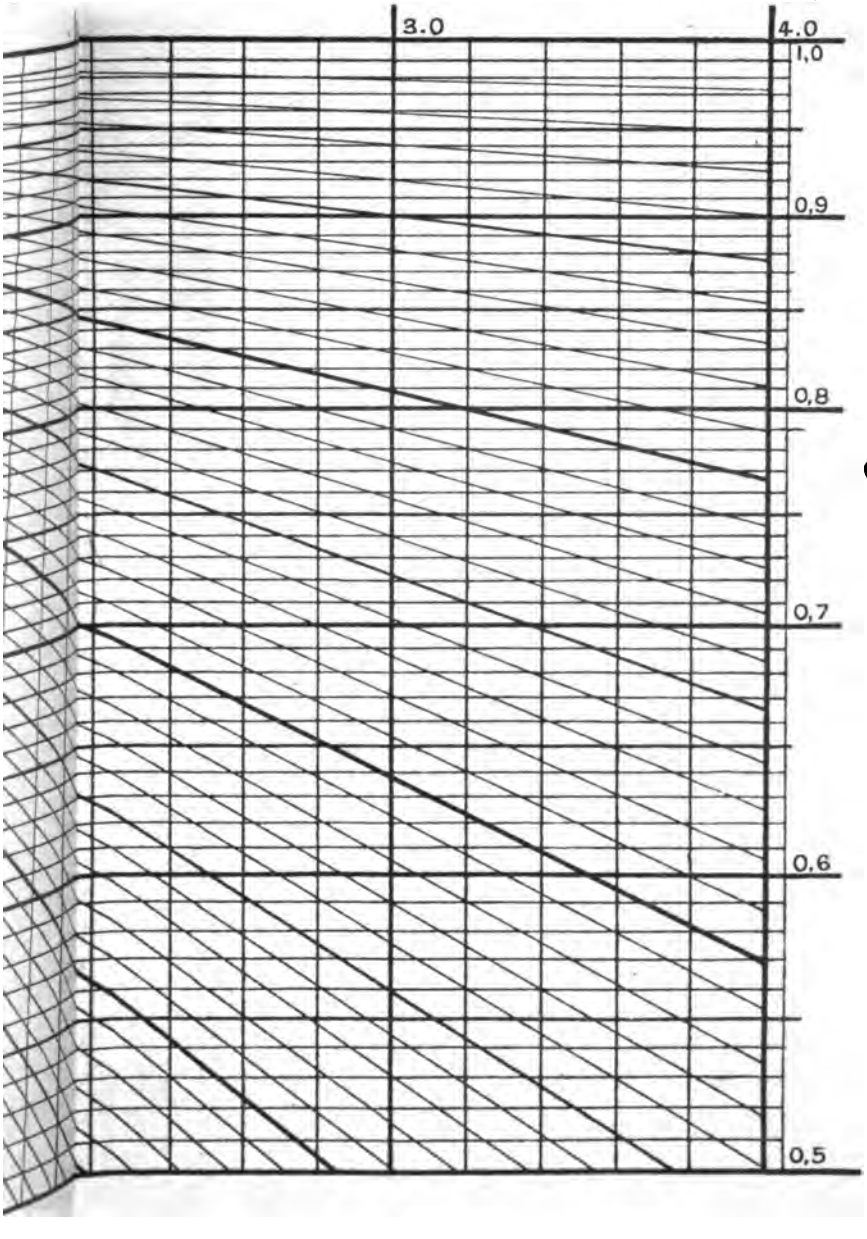
It is to be hoped, in conclusion, that the naval and military officers and the constructional engineers will in the future see that methodical trials are organised in order to determine for the principal objectives which may be met with during a war the average values of the coefficients which are contained in the general formulæ given by M. Blondel, and which alone will make it possible to determine with absolute accuracy the calculations of the ranges of electric searchlights.

DIAGRAM FOR THE CORRECTI

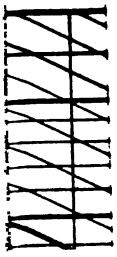


RRECTIO OF THE COEFFICIENT a.

OF THE RATIO $l' : l$ --



VALUES OF a --



by an inclined straight line. It is easy to see that for a 20 millimetre carbon, for instance, the maximum intensity would reach 165 amperes. Moreover, only with carbons of special

APPENDIX

NOTE A

The Determination of the Diameter of the Crater as given by Formula No. 7 and with the Assistance of a Graphic Diagram

The formula No. 7, which gives the diameter of the positive carbon crater δ as a function of the diameter D of the carbon, and of the intensity I in amperes, is as follows :

$$\delta = 0{\cdot}344\sqrt{DI}.$$

It is easy to represent this formula by a graphic diagram (Fig. 34) in such a manner as to make it possible to directly read every calculation at sight.

It will be observed that in Fig. 34 the horizontal scale gives the diameter of the positive carbon in millimetres, the right-hand vertical scale, the diameter of the crater, and the left-hand vertical scale, the intensity in amperes.

Knowing the diameter of the carbon, say 20 millimetres, and the intensity in amperes, say 50 amperes, it will at once be seen that the diameter of the crater δ is 12 millimetres.

The same curve also gives the maximum current admissible, and which, for the carbons usually employed, corresponds to a diameter of the crater equal to the diameter of the positive.

Assuming that $\delta = D$, it is found that

$$\delta = (0{\cdot}334)^2 \, I, \qquad \text{or } \delta = 0{\cdot}118 \, I, \qquad \text{or } I = 8{\cdot}45 \, \delta.$$

This maximum current intensity is represented in the diagram by an inclined straight line. It is easy to see that for a 20 millimetre carbon, for instance, the maximum intensity would reach 165 amperes. Moreover, only with carbons of special

construction would it be possible for a current of 165 amperes to flow through a 20 millimetre carbon.

NOTE B

The Use of the Graphic Diagram in Fig. 8, where the Distances l and l' are Unequal

The curve in Fig. 8, which summarises the equation of ranges, represents the case where the distance l between the search-light and the objective is equal to the distance l' between the objective and the observer.

It is not possible, however, to directly make use of this curve in the general case where the two distances are no longer equal—for instance, in the case where $l = l'$ the equation of ranges is written as follows :—

$$\frac{\epsilon_o}{\epsilon_p} = \frac{a^{2l}}{l^2}.$$

In the case where l is different from l'

$$l' = \alpha l_1.$$

The equation of ranges will then become

$$\frac{\epsilon_o}{\epsilon_p} = \frac{a(1+\alpha)\,l_1}{{l_1}^2}.$$

By taking the logarithms of the two members of these two equations of ranges they will give

$$\log \frac{\epsilon_o}{\epsilon_p} = l \log a^2 - 2 \log l$$

$$\log \frac{\epsilon_o}{\epsilon_p} = l_1 \log a\,(1+\alpha) - 2 \log l_1.$$

It will at once be seen that these two equations are analogous. The value l_1 that is to say, the new distance between the search-

light and the objective, may be read on the same scale as l, provided a be represented by the transformed value

$$a' = a_1^{\frac{2}{1+\alpha}}.$$

M. Batifoulier, who communicated this solution to us, has drawn up the diagram (Fig. 33) which gives the value of a'.

The following is the manner in which this diagram must be used :

Assume that the coefficient of transparency is known, as is also the first member of the equation of ranges, that is, $\frac{\epsilon_0}{\epsilon_p}$.

In the case where $l = l'$ it is easy to determine the value of range by the aid of the diagrammatic curves in Fig. 8.

In a general case in which l is no longer equal to l', let it be assumed, for instance, that the ratio $\frac{l'}{l}$ is equal to 2. The curve in Fig. 8 must be read in the usual way, but with a value of the transparency coefficient a' instead of a, which is indicated in the second curve of Fig. 33.

From the scale placed horizontally at the top of Fig. 33, and which gives the value of the ratio $\frac{l'}{l}$, the value 2 can be obtained.

On the other hand, knowing that the coefficient of transparency corresponding to the value required is 0·8, this value of 0·8 can be read on the vertical straight line corresponding to $\frac{l'}{l} = \text{I}$.

The inclined straight line, which starts from this point and again cuts the vertical straight line 2, corresponds on the right-hand vertical scale to a value of $a' = 0{\cdot}72$ approximately, or, to be exact, 0·714.

This value $a' = 0{\cdot}714$ is that value which will have to be used with the curve in Fig. 8 in order to determine the value of the range, the ratio $\frac{\epsilon_0}{\epsilon_p}$ being known through other considerations.

NOTE C

Optical Illusion produced by the Illumination from a Searchlight on Observers situated within the Beam

An optical illusion which is of very frequent occurrence is produced at a distance by the illumination from a searchlight on observers situated within its beam.

It very often happens during military operations that troops of infantry, pioneers making trenches during the night, convoys, aviators, etc., caught by the beam from a searchlight placed at a great distance, and finding themselves often very brilliantly illuminated, imagine that they are visible to the enemy and that they must take cover.

It appears to be of considerable importance to analyse this phenomenon, which is likely to demoralise observers who are not familiar with the employment of searchlights, and also to disturb useful operations which the command might prescribe.

Take the following example. During the present war an aviator, entrusted with a night operation over the enemy lines in Belgium, declared that he was illuminated at a distance of 12 kilometres by projectors of very high power, so much so that it was necessary for him to exercise all his ingenuity to escape from the beams of these searchlights.

Now, if the enemy artillery had been placed in the vicinity of the searchlights, practically at the same distance from the objective (the aeroplane in question) as the illuminating apparatus, it is easy to see that in no case could the aeroplane be seen.

Let it be supposed that a light-coloured aeroplane, having a spread of 12 metres, can be compared as regards its details and illumination to that of a light-coloured building of similar dimensions. It has been previously found that the equivalent illumination corresponding to such an objective is 0·23 lux for the limit of visibility with glasses.

Taking this value, which certainly does not exceed the actual value, it will be found that for a coefficient of atmospheric transparency of 0·85, which may well be considered to corre-

spond to the average in winter for Flanders, a practical illumination of 622 lux at 1,000 metres would be required in order to obtain a range of 12 kilometres. For such an illumination a searchlight having a diameter of 4·75 metres would be necessary, whereas the most powerful searchlight in use by our enemies on the battlefield does not exceed 1·10 metres in diameter, and which gives under the most favourable conditions a practical illumination of 50 lux at a distance of 1,000 metres.

On the other hand, the illusion of an aviator who thus finds himself caught at a distance of 12 kilometres in the beam from a searchlight is caused by the illumination to which he is subjected.

With the case in question, what is the amount of this illumination ? The reduction of the practical illumination from the searchlight at a distance of 1,000 metres, after having traversed 12 kilometres through the atmosphere having a coefficient of 0·85 and taking into account the reduction due to the square of the distance, will be of approximately 1/1,000, that is to say, the observer will receive a degree of illumination about 1,000 times less than that from the searchlight. Thus, a 1·10 metre searchlight will project on to the aeroplane an illumination of 50/1,000, or 0·05 candle-power.

Now, the full moon at its zenith gives 0·20 candle-power.

The intensity of this illumination on the areoplane will therefore be only one-fourth of that from the full moon at its zenith and will approximately correspond to the full moon at 20° above the horizon.

Such an illumination makes it possible to see the time on a watch, and it is readily comprehensible that an observer, placed within a beam giving that degree of illumination, must feel that he is discovered by the enemy, whereas the latter, at a distance of 12 kilometres, is absolutely unable to perceive him.

Take another example. On the Western front our soldiers, who were digging a trench at night at a distance of 7,600 metres from a German searchlight 0·90 metre in diameter, were illuminated somewhat brilliantly and withdrew, fearing to be hit by the enemy fire.

Now, allowing for a good coefficient of transparency, 0·9 per kilometre, and bearing in mind that under the most favourable conditions a 0·90 metre searchlight gives a practical illumination of 37 lux with high voltage carbons, and taking into account that the equivalent illumination of a trench is approximately 0·5 lux, it will be found that, supposing the observers to be placed at the same distance from the objective as the searchlight, the useful range would be 3,650 metres.

It was therefore absolutely impossible for the enemy, unless he came very much nearer, to be able to distinguish the trench. On the other hand, the illumination to which the workers were subjected corresponded at the distance of 7,500 metres to 0·296 lux.

It is easy to understand that under these conditions they were sufficiently illuminated to justify them in supposing that the enemy could observe them, seeing that such a degree of illumination was approximately equal to one and a half times that which would have been given by the full moon at its zenith.

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